Enterprise Mobile Infrastructure 2018

Abstract:

Enterprises are starting to buy wireless in-building solutions for licensed LTE bands, creating a new growth market with huge potential. This report provides guidance on which solutions fit with various vertical markets based on traffic density, revenue density, and the ease of use for each wireless solution.

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ENTERPRISE MOBILE INFRASTRUCTURE

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1 EXECUTIVE SUMMARY

The Enterprise Mobile Infrastructure market is in limbo as the market transitions from top end of the market to "mid" markets across the different vertical industries. The growth in the top end of the market, mainly comprised of stadiums and airports, is flatlining in developed markets as most key venues have already been retrofitted with cellular in-building wireless (IBW) systems. Meanwhile, price-sensitive "mid" enterprise markets have been tough to crack with "full-blown" DAS products and business models that are too pricey and cumbersome for enterprises to navigate.

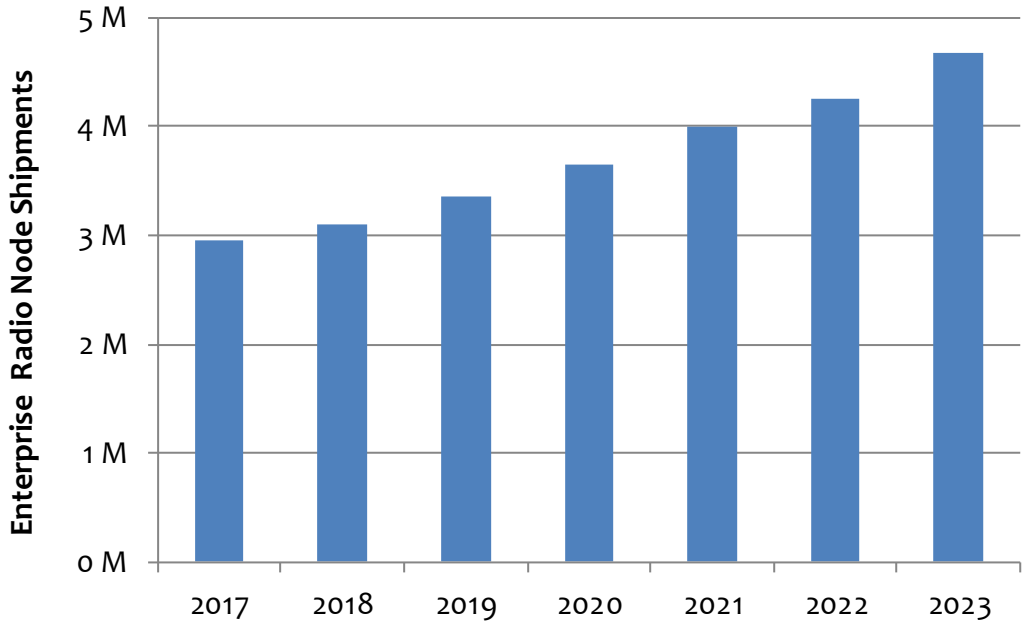
Clearly, the market is demanding a new solution and streamlined business model to truly open the "mid" market for cellular in-building wireless solutions. In the meantime, DAS and booster products are addressing the "top" and "bottom" ends of the enterprise market in terms of size of coverage and volume of capacity needed at a venue. Meanwhile, the market still awaits the "right" product solution, but just as important, the "right" business model to open up this "mid" market opportunity at scale.

Vendors from various segments of the enterprise wireless infrastructure market are taking different approaches to the "mid" market in-building wireless solution. Traditional DAS vendors are introducing cost-optimized *Light DAS* solutions that selectively limit the number of frequency bands to lower equipment cost and leveraging structured Cat 5/6 cabling to limit the cabling/installation labor costs. Meanwhile, traditional booster or repeater vendors are introducing multiband "enterprise" boosters or *Smart* (networked) *Booster* solution to extend coverage more uniformly for higher performance. Traditional small cell and Wi-Fi infrastructure vendors are looking to leverage the CBRS shared spectrum to bring "multi-operator" small cell solution. Furthermore, some vendors are looking to *VRAN* to bring virtualized baseband processing which can be coupled to a DAS system as a fully integrated system. A key theme around these innovations is that both signal source (for capacity handling) and distribution methods (for RF/signal distribution) are being disintermediated and put together to form the "right" in-building wireless solution for the different vertical industries with varying coverage and capacity requirements. The Light DAS, *CBRS Small Cell*, *Smart Booster*, and *VRAN+* solutions are essentially different forms of distributed radio systems with different signal source types to optimize for the different capacity requirements.

In this report, Mobile Experts has analyzed eight different vertical industries and the capacity and coverage requirements of each based on our estimate of average venue size and traffic profile. Based on our estimate of the fully installed costs for "distribution" and "capacity" handling of the various in-building wireless solution combinations, including Heavy and Light DAS, CBRS Small Cell, Operator-specific Licensed Small Cell, Smart Booster, Macro BBU, and VRAN BBU, we have identified suggested primary and alternative IBW solutions based on the initial CAPEX costs. Generally, our analysis suggests that very large public venues requiring high capacity demand would be better served with traditional DAS

plus Macro BBU solution while low capacity-density venues can be served well with Smart Booster plus "Off-air" and Small Cell combinations. Once CBRS or MulteFire Small Cells become more mainstream, we believe this can serve a big swath of the "mid" market, but this depends on how willing the operators are to support this paradigm.

Despite the challenges of complex business models that hinder direct enterprise deployment of in-building wireless solutions, the market continues to grow. Mobile Experts forecasts the *Enterprise Mobile Infrastructure* equipment market will grow at 8% CAGR in unit shipments from 2017 to 2023. The biggest growth is expected to come from the Small Cells category, including DRS and enterprise units, growing at over 20% CAGR from 2017 to 2023. Meanwhile, we are forecasting a slight decline for traditional DAS category at (3%) CAGR as the growth driver of large venue installations decline especially in North America. Booster unit shipments, while small in absolute number of units, is expected to grow at a healthy 17% CAGR as the "Smart Booster" is expected to widen the addressable market opportunity for this product category.



Source: Mobile Experts

Chart 1: Growth of Enterprise Mobile Infrastructure, 2017-2023

In revenue terms, the market is expected to grow from over $2.9B in 2017 to $3.6B in 2023 – a modest 3% CAGR. As the market transitions from top venues to large numbers of mid-market opportunities, DAS segment is expected to fall from almost 56% of the total Enterprise Mobile Infrastructure equipment revenue in 2017 to 33% in 2023. Meanwhile, the Small Cells revenue share will increase from 32% in 2017 to 48% in 2023. The Booster revenue

share is expected to grow from 12% in 2017 to 19% in 2023 as the market transitions to serving smaller enterprises and venues.

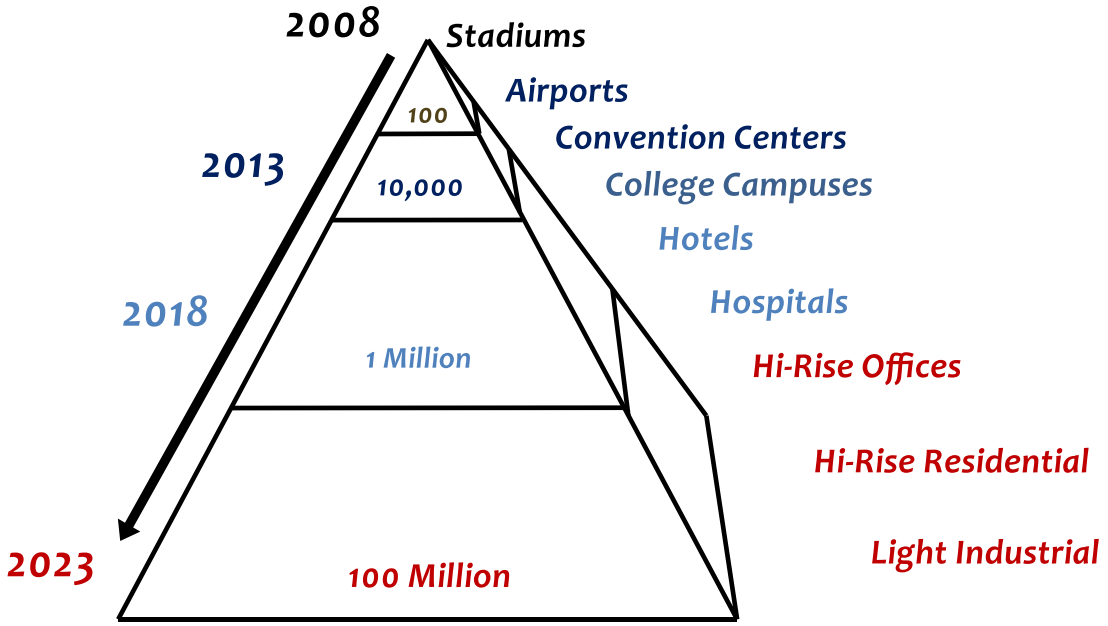
Our forecast model assumes the current business model of "project-by-project, building-by-building" deployment of in-building wireless solutions. If the market dynamic changes to a more scalable model in which the operators or major neutral-host providers take significant active roles in building out "mid" market venues, then our projections can move up significantly, and the share mix of Signal Booster, Small Cell, and traditional DAS categories will change.

2 ENTERPRISE MOBILE INFRASTRUCTURE MARKET TRENDS

The *Enterprise Mobile Infrastructure* market refers to cellular in-building wireless infrastructure equipment market. While Wi-Fi is widely recognized by enterprises as a de-facto wireless solution for indoors, cellular in-building systems are not well understood. Delving into the details of cellular frequency bands, 2G/3G/4G/5G technology choices, distributed vs. centralized architecture choices can be daunting for IT staff who are used to mounting Wi-Fi access points and turning them on for quick provisioning. In fact, most projects today are executed without a careful review of what technology option provides best near-term and long-term solution for how mobile infrastructure should be provisioned based on usage.

Enterprise Verticals

The diagram below illustrates the migration of in-building market trend from large public venues like stadiums to smaller commercial buildings. (We first created this chart in 2009 and it's still on track!) The overall market trend is trending downward to smaller venues like hotels, hospitals, high-rise commercial buildings and higher education campuses as mobile coverage and capacity is increasingly becoming important not just in large venues like stadiums, but everywhere else, as consumers and workers increasingly rely on their mobile devices for many aspects of life and work.



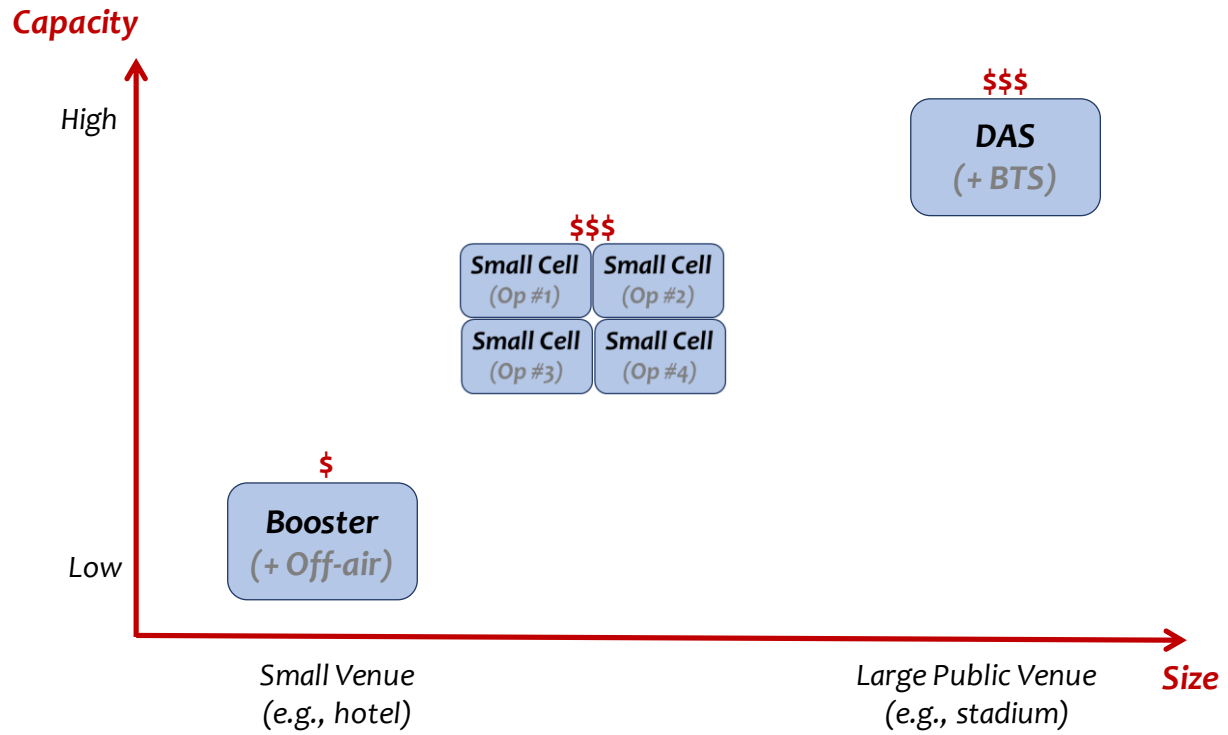
Source: Mobile Experts

Figure 1. Illustration of Enterprise In-Building Market Trend

Today's Cellular In-Building Wireless Solutions

Historically, the cellular in-building wireless (IBW) market evolved from the needs of operators to put in place highly dense cellular infrastructure at large public venues like stadiums and airports to handle the large volume of traffic. This is where the DAS was "born", to extend the mobile coverage indoors (in venues) to handle the large capacity required at those sites. As the need for area footprint to place all those remote radios and antennas kept increasing, it became clear to venue owners and operators alike to leverage "shared" infrastructure system like DAS to provide mobile wireless coverage across all major operators and multiple frequency bands that each operator uses to carry its mobile services. Hence, DAS naturally occupies the "high-capacity, large-venue" corner of the cellular IBW landscape as shown below.

On the other end of the spectrum, repeaters or boosters have provided low-cost alternative for low-traffic, small venues, typically less than 50K sq. foot. At these low-density, small venues, the capacity requirement is generally so light that "borrowing" Macro tower capacity nearby for baseband handling is deemed okay. It should be noted, however, that using booster and donor antenna (for "off-air) at venues in urban areas are sometimes frowned upon by the operators who sacredly protect their Macro outdoor network.

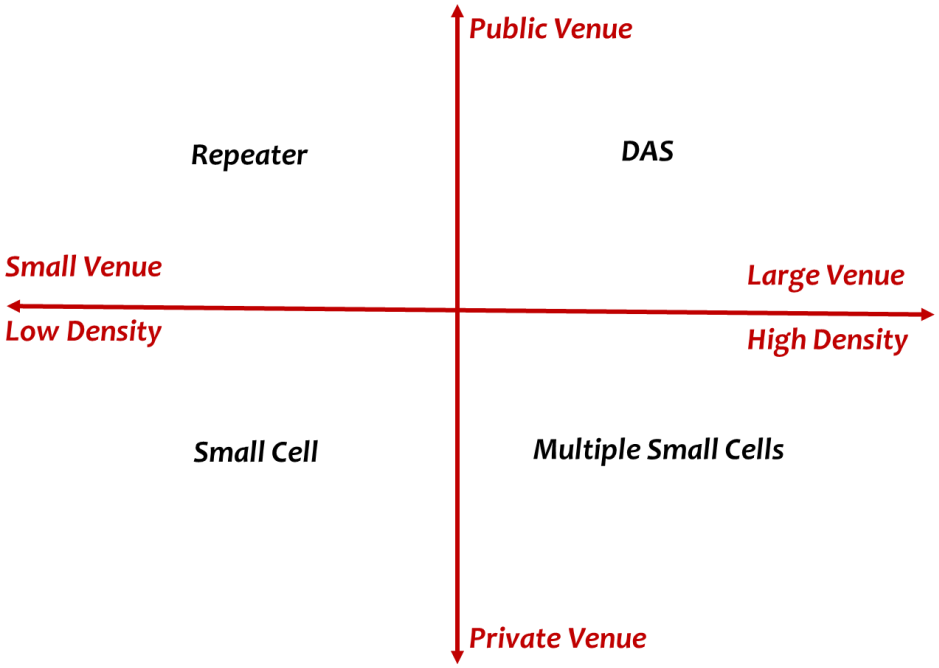


Note: Multiple operator-specific small cells are needed to support the multi-operator requirement

Source: Mobile Experts

Figure 2. Today's Cellular In-Building Wireless Solutions and Their Market Fit

While small cells have been introduced in the recent years, Enterprise small cells are generally viewed as single-operator solutions. Hence, to provide the multi-operator support, multiple small cells are needed. This "stacking" method adds to the initial CAPEX cost as well as management overhead in on-going maintenance.

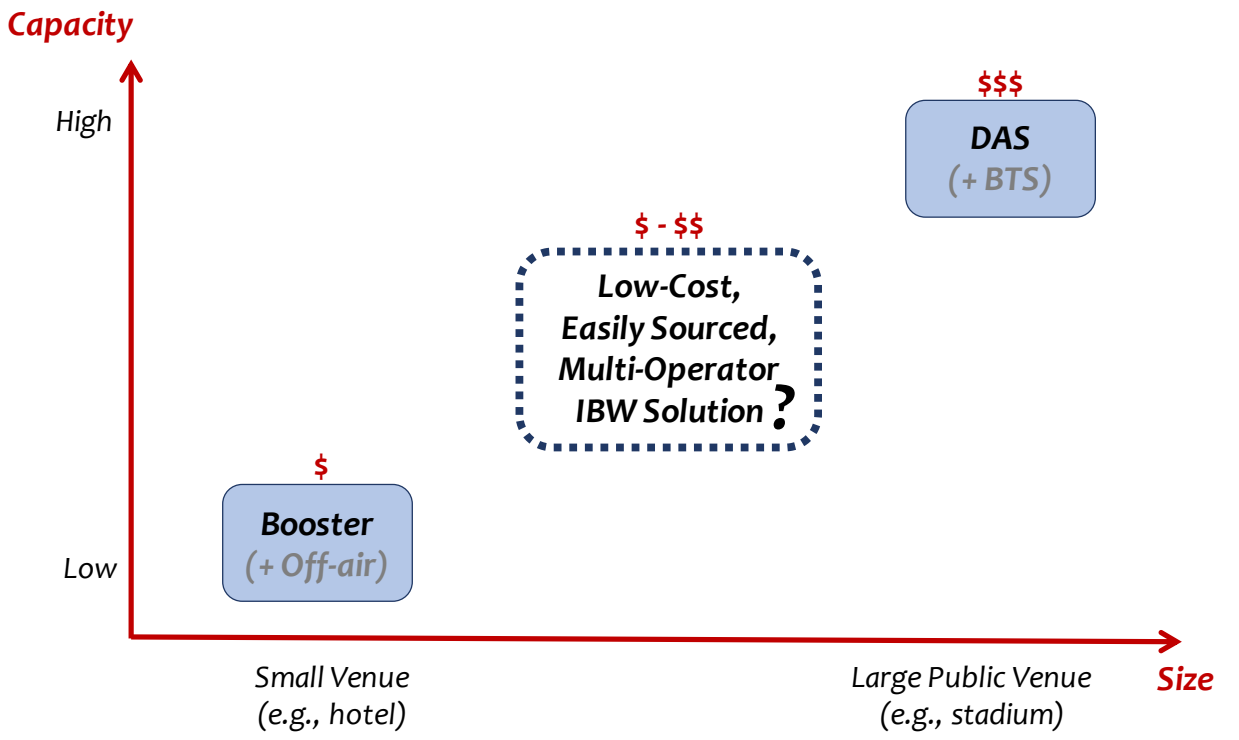


Source: Mobile Experts

Figure 3. Traditional DAS, Small Cells, and Repeater Market Fit

What's Missing?

While there is a general agreement that today's IBW solution landscape addresses the very high end and the very low end, it does not adequately provide cost-effective solution for the "mid" market such as hotels, hospitals, and other commercial venues with a wide range of capacity and coverage needs.



Source: Mobile Experts

Figure 4. Missing Cellular IBW Solution for the "Mid" Market

3 IN-BUILDING WIRELESS TECHNOLOGY OPTIONS

As mentioned previously, the cellular in-building wireless (IBW) solutions have historical roots in usage and applications:

- Distributed Antenna Systems (DAS) – for very large, high-traffic public venues
- Small Cells and RRH – for mid-size venues requiring scalable single-operator solution
- Boosters (repeaters) – for small, low-traffic venues to simply extend coverage
- Wi-Fi - for "best effort" wireless connectivity to the Internet

Signal sources that drive the cellular IBW solutions have historically been implicitly assumed to be Macro base station for DAS and "off-air"[1] for Boosters. Meanwhile, Small Cells and Wi-Fi inherently contain signal source, or capacity handling capability, embedded in the radio units.

As the Enterprise In-Building market goes "down-market" towards "mid" size venues such as hi-rise buildings, hospitals, and other industrial complexes, vendors from the traditional DAS, small cell, and booster markets are innovating along the "RF distribution" and signal source "capacity" dimensions as shown below. Some vendors are taking the active DAS approach by networking multiple remote radio units to a central unit to cover bigger areas by uniformly distributing RF signals. Similarly, some Tier 1 small cell vendors are extending the RRH architecture to bring Distributed Radio System (DRS) products to market. A key theme in all these innovations is to "right size" capacity handling along with RF/signal distribution to optimize the CAPEX and OPEX costs.

(+)		Signal Source (Capacity handling)				
		Off-air	Small Cell	VRAN BBU	Macro BTS	CRAN BBU
RF distribution (Coverage handling)	BDA Booster	■				
	"Smart" Booster	■	■			
	Distributed Radio System (DRS)					■
	"Light" DAS	■	■	■		
	"Heavy" DAS			■	■	■

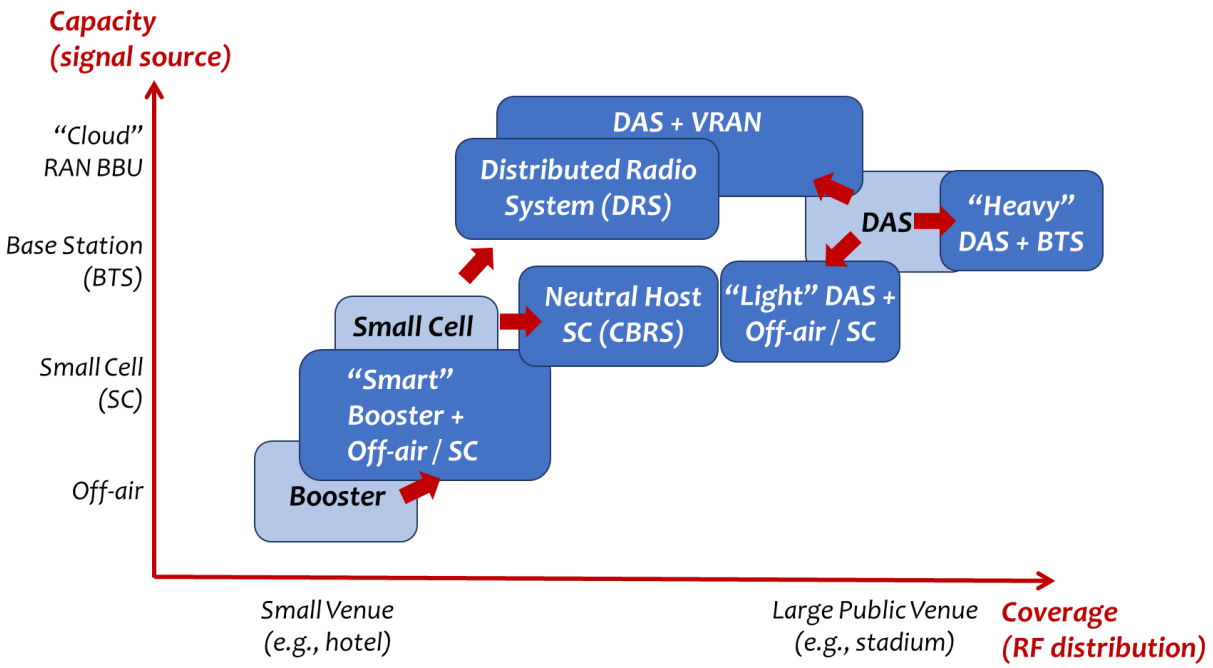
Source: Mobile Experts

Figure 5. Permutations of IBW solutions by "RF distribution" and "signal source" methods

Along the traditional RF or signal distribution side of the equation, vendors are introducing different cellular signal distribution methods, including means to leverage existing structured cabling found in many enterprise verticals. For example, the "Smart" Booster solution, active DAS, and DRS systems all look to leverage structured Cat 5/6 cables to distribute power and signal to remote radio units. Along the "signal source" side of the

[1] The signal source is derived from nearby macro base stations outside

equation, some vendors are looking to virtualize baseband processing on commercial off-the-shelf (COTS) servers. This approach leverages Moore's Law economics of running BBU software on standard data center servers--which continue to bring higher performance at lower prices. While there are certainly key technical and business challenges associated with the new innovations and solutions, there appears to be a growing proliferation of signal source options and distribution methods, which in turn expand the cellular IBW solution options beyond simple DAS or Boosters, into a rich array of "Heavy" DAS/ "Light" DAS/ "Smart" Booster combinations with Off-air/ Small Cells/ CRAN and VRAN BBUs as shown below.



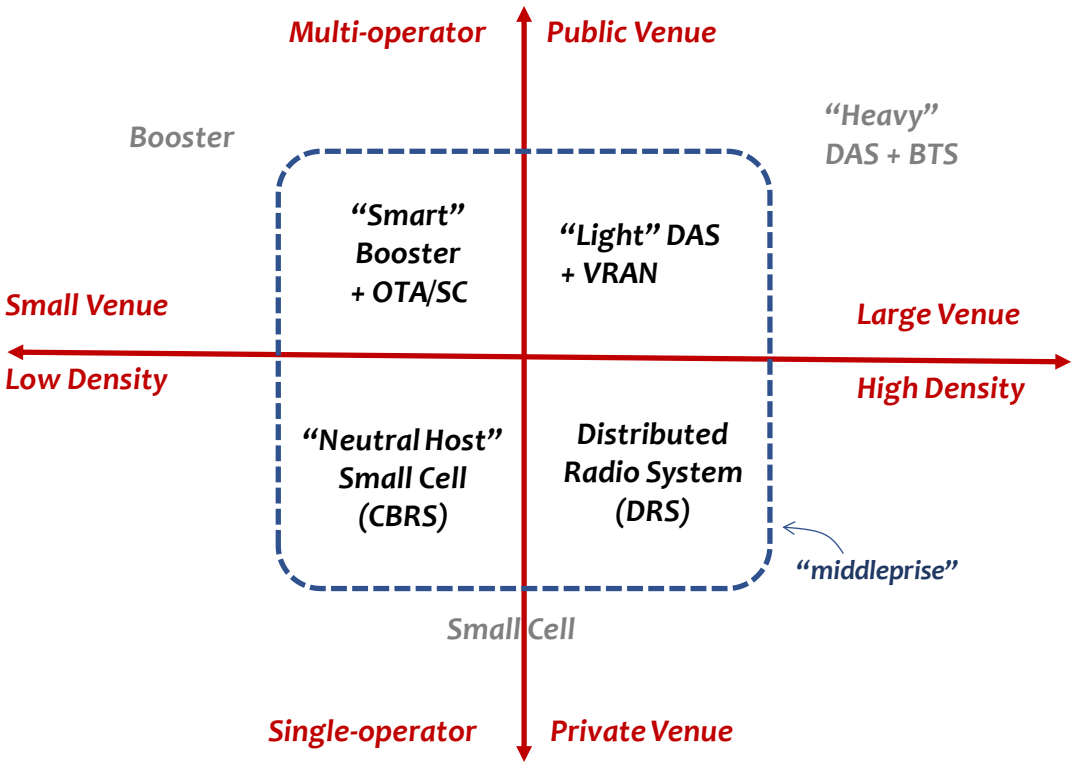
Source: Mobile Experts

Figure 6. Expanding Cellular In-building Wireless Technology Options

The complex array of "RF distribution" and "signal source" combinations as depicted above can be illustrated in the following product-fit diagram--which shows each architecture's ability to address the different coverage/capacity requirements and the multi-operator aspect.

- The "Smart Booster + OTA" solution extends coverage of standalone BDA booster (highlighted in gray in the below diagram) by creating a network of remote radio units which work in concert with central unit to extend uniform coverage and improve SINR.

- The "Light DAS + VRAN" solution can lower the CAPEX cost by supporting a limited number of bands/operators on the active DAS system and drive that system with lower VRAN BBU source.
- A "Light" DAS system can be driven by operator-approved small cells for venues that have lower capacity requirements.
- CBRS Small Cells can theoretically provide a much lower CAPEX by leveraging a common CBRS band as operating indoor frequency across all operators in which case a single CBRS Small Cell can serve all operators who adopt this method. (CBRS applies in the American market, but the same concept could work with MulteFire or another shared LTE band in other countries).
- DRS system can extend Macro incumbent vendors' BBU capacity to provide "macro parity" across indoor-outdoor transitions.



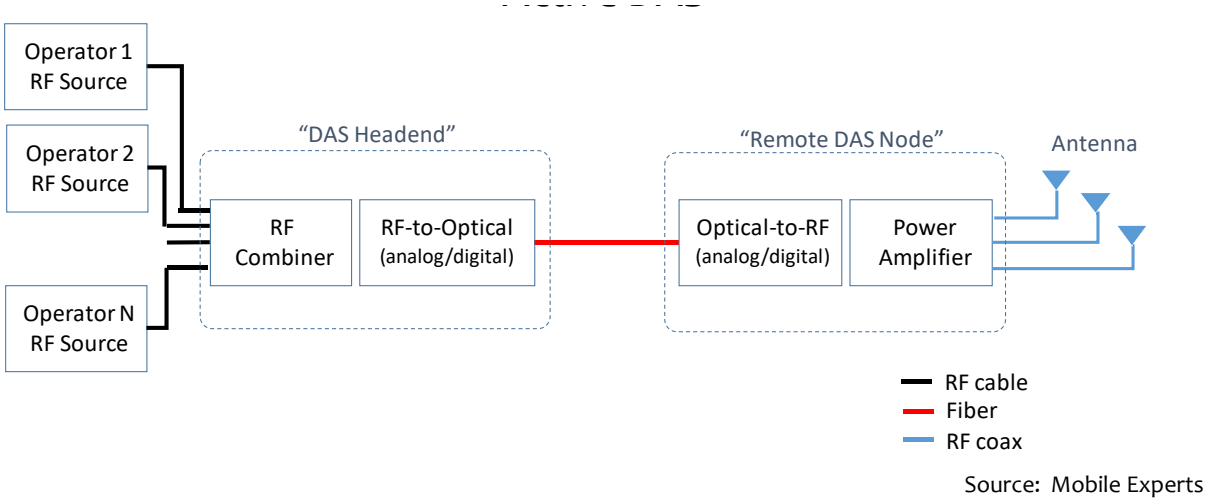
Source: Mobile Experts

Figure 7. Expanding Cellular IBW Solutions for the "Middleprise" Market

Distributed Antenna Systems (DAS)

A DAS system combines multiple radio signals, then distributes the signals to multiple antenna locations. A headend system effectively converts RF through IF down-conversion to an optical signal that is transported over a fiber optic cable to a remote unit, which

converts it back to RF, amplified and transmitted via antenna. The RF-to-optical conversation provides better protection against passive intermodulation (PIM) interference, found in old Passive DAS systems. Hence, most large DAS projects involving multi-operator, multiple frequency bands typically deploy Active DAS architecture as shown below.



Source: Mobile Experts

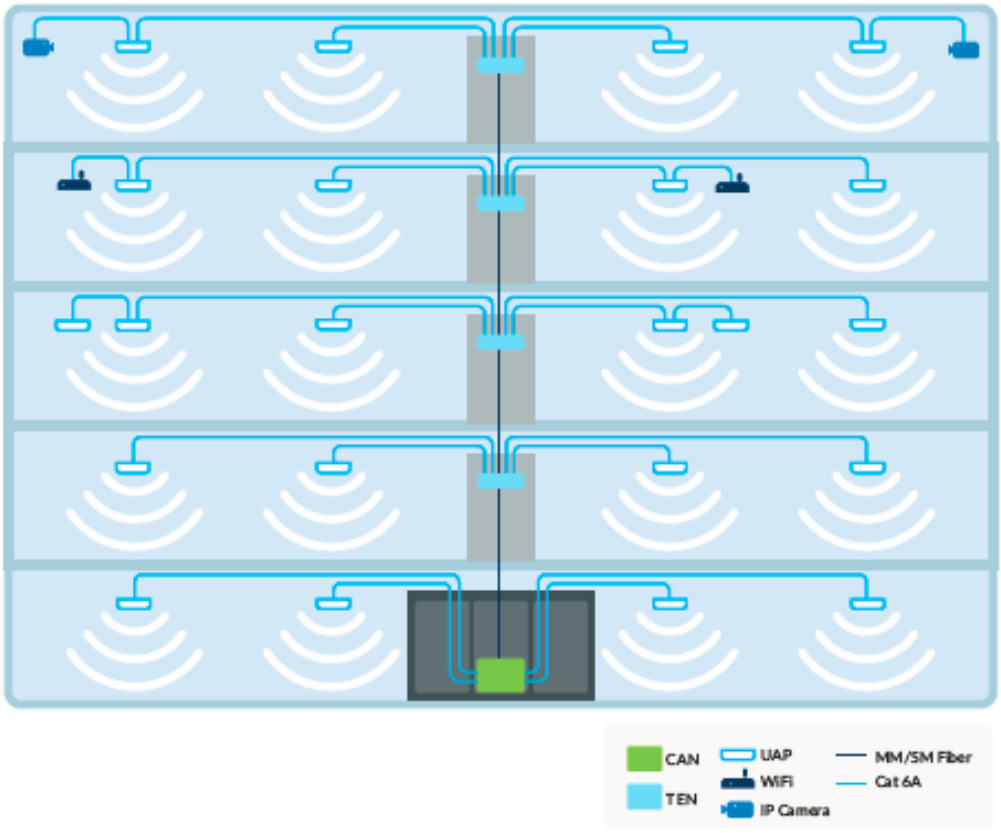
Figure 8. Active DAS System Architecture

A typical DAS system today does not include a signal source, so a DAS project typically involves procurement and installation of the DAS, followed by installation of a signal source for each mobile operator. To balance the cost vs. performance (and multi-operator) tradeoff, we believe the traditional DAS segment can be partitioned into:

1. "Heavy DAS" segment -- in which all major operators and up to 8 different frequency bands are supported
2. "Light DAS" segment – in which only one or two operators and one or two bands per operators are supported

By selectively limiting the number of bands (and operators) supported on each Remote DAS nodes, the total CAPEX cost can be meaningfully reduced, not to mention the long cycle time required to source signal sources from each of the operators.

In certain vertical venues where heavy capacity handling is not necessary, a mid-size hotel, for example, operator-approved small cells may be sufficient to drive a "Light DAS" system instead of a large macro base station.



Source: Commscope

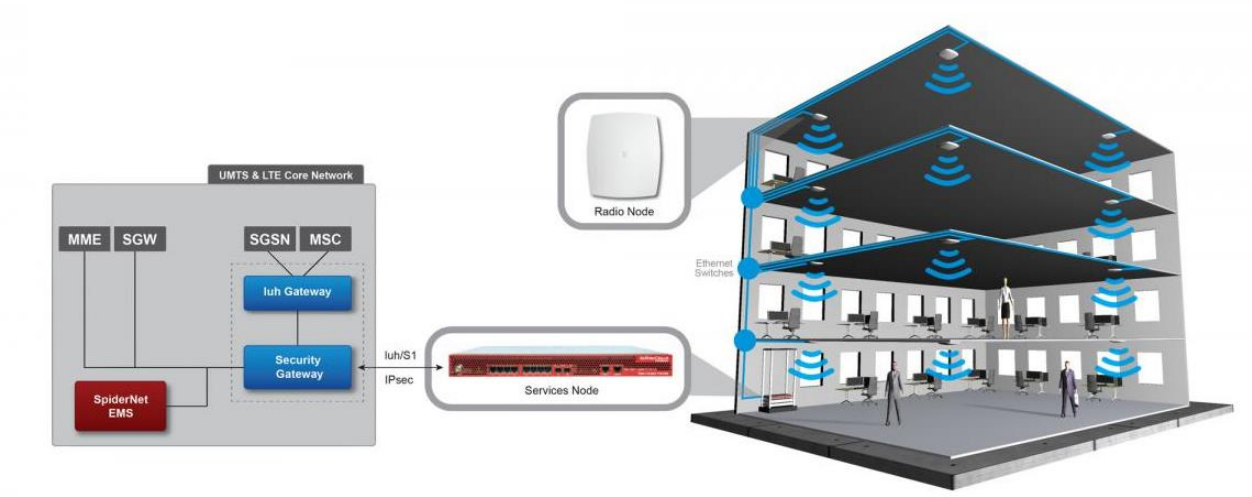
Figure 9. Typical DAS Architecture

For enterprises, DAS projects can be frustrating and challenging to manage. An enterprise can buy a DAS and install it anytime, but must also convince the mobile operators to support signal sources to feed the DAS system. Coordinating DAS projects with mobile operators and securing backhaul for macro base station connectivity back to operators' core networks can be frustrating and uncertain at times. To remove some of these complexities, especially for smaller venue projects, some vendors are looking to incorporate VRAN BBU combined with "Light DAS" products to provide low-cost solutions to the market. JMA Wireless' XRAN initiative is a good example of this trend.

Small Cells (Operator-Specific and Neutral-Host CBRS)

Small cells are becoming active extensions to macro networks. As mobile traffic usage continues to rise, operators are scaling their mobile networks at the "edge" to capture and deliver traffic where the users are. As an integrated system that delivers baseband processing necessary to create 3G/4G signal (and presumably 5G in the next few years) and radio components necessary to transmit and receive the signal locally, small cells offer scalable means to grow the radio network. In terms of indoor deployments, baseband and radio processing are typically handled locally on radio node units. For simplicity of

installation and to reduce cabling costs, most enterprise-focused small cells use Ethernet cabling for transport and power via Power-over-Ethernet (PoE). Further, a centralized controller is often used for provisioning and aggregation of small cell radio nodes in a premise back to the mobile core network.



Source: SpiderCloud

Figure 10. Small Cell (RRH) Architecture

Today, multiband small cells typically handle a single operator with one or two operating frequency bands. It is possible to implement multi-operator coverage using small cells, using techniques to share resources at a radio level (MORAN) or at a core network level (MOCN). However, most mobile operators, outside of Europe, generally do not like to share active network components. Hence, these RAN sharing approaches are not widely adopted. Several small cell products have been approved by major operators for enterprise use. Some examples include Spidercloud, Samsung, Nokia, etc. In some instances, system integrators adopt operator-approved small cells to drive DAS systems. Leveraging small cells for indoor environments with less-demanding capacity requirement than stadiums, for example, can bring the total CAPEX as well as OPEX costs by not having to deal with large power and backhaul costs associated with Macro as signal source.

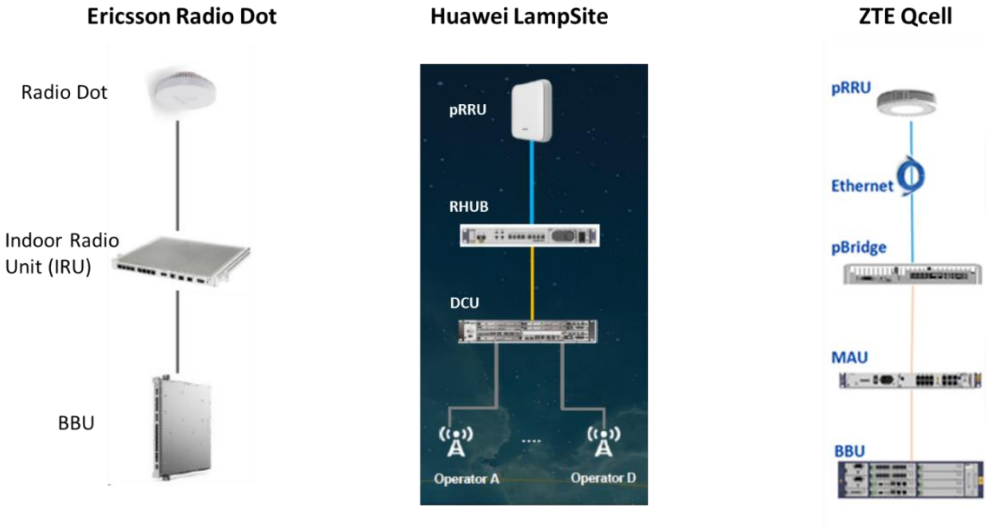
One of the interesting developments in the Enterprise Mobile Infrastructure space in the past year has been the development of the CBRS ecosystem. Small cells leveraging the CBRS band in the USA have the potential to provide a "neutral host" small cell to fill a void in the marketplace between Wi-Fi and DAS. Assuming that all major operators adopt and support the CBRS band for mobile services, a single CBRS small cell can service multiple operators. Instead of placing multiple small cells (one for each operator) at each remote site, an enterprise or a neutral host provider can place a single small cell to serve all major operators.

CBRS small cells, with inherent multi-operator support and simplicity of Wi-Fi like installation, can provide a cost-effective mobile coverage solution for third-party neutral host providers and enterprises alike.

Distributed Radio Systems (DRS)

Distributed Radio Systems (DRS) like Huawei's LampSite, Ericsson's Radio Dot, and ZTE's Qcell take the Centralized RAN architecture concept with low power RRH radio units one step farther. Instead of an RRH feeding an antenna directly, in the DRS architecture, the RRH leads to a series of distributed RF antenna nodes to distribute RF signals "deep" within indoor venue locations. This is very similar in concept to other "distributed" systems like DAS. While the architecture and functional aspects of DRS is similar to an active DAS system, Mobile Experts has generally viewed DRS as a single-operator system vs. multi-operator capabilities for DAS.

The DRS systems consists of a baseband unit (BBU), a radio head unit hub (Hub), and multiple remote radio units (RRUs). For example, a Hub is called Indoor Radio Unit (IRU) in Ericsson's Radio Dot and Remote Hub (RHUB) in Huawei's LampSite parlance. In the DRS architecture, multiple remote radio units can serve one cell with each cell individually served by each remote radio unit, which increases SINR. A Hub unit provides power and control up to eight RRUs and is frequency band independent. A Hub separately demodulates signals from multiple remote radio units and then combines the signals in the BBU without increasing background noise. Typically, the macro parity aspect of DRS architecture from Tier 1 vendors is a big advantage as this allows closer coordination with macro networks outside to reduce operations and management costs.



Source: Ericsson, Huawei, ZTE

Figure 11. DRS Small Cell Architectures

In the past year, the DRS vendors introduced the "multi-operator" feature whereby multiple operators can share a DRS system already deployed in a building or venue. Essentially, the idea is for additional operators to "plug in" to existing DRS systems. To accommodate this feature, a new network element called RF-Access Unit (RAU) in Ericsson's Radio Dot architecture and Distributed Control Unit (DCU) in Huawei's LampSite architecture, is introduced to convert external RF signal to digital CPRI. While this "multi-operator" DRS feature provides added flexibility and appeal for markets that are favorable to RAN sharing concepts, Mobile Experts believes that this would have a limited appeal in competitive markets like the North American region where operators are less prone to sharing active network assets.

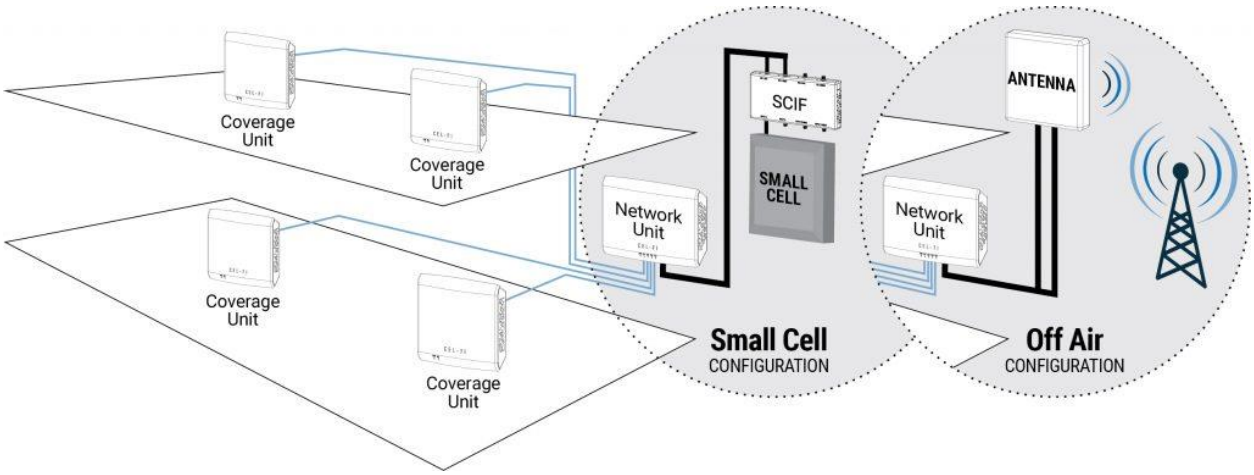
Tier 1 vendors like Ericsson and Huawei are positioning DRS as a scalable indoor system for a wide variety of venues from "mid" market to even highly dense stadium markets. The fact that operators can leverage existing Macro CRAN BBU to drive both outdoor and indoor systems provides added flexibility and potential cost savings from pooling gain. However, a key drawback, especially in North American market, is that these solutions are generally viewed as single-operator systems. Even in the "multi-operator" configuration, the same vendor (e.g., Ericsson, Huawei, etc.) BBU needs to feed the DRS system. This implies that in order to support multi-operator aspect, the DRS owner/maintainer must leverage the same vendor BBU solution as well.

The DRS system can also function like a DAS, with one operator's BBU feeding their service and other operators providing RF signal sources. This feature is available now but we see little traction, as the top tier OEMs are not accustomed to selling DAS.

Boosters (Repeaters)

Boosters or repeaters are the simplest infrastructure to create mobile coverage. A repeater essentially boosts a signal to/from a nearby macro base station, extending the range of the outdoor network inside. A careful placement of the repeater's antennas can improve indoor coverage. The repeater's donor antenna can be placed nearby a window or on a rooftop to improve signal reception and re-transmission inside a building.

Boosters are widely available through system integrator and reseller channels. Most enterprise-class boosters are approved by the regulators and sometimes endorsed by mobile operators so that an enterprise can either directly buy the booster from a supplier or a reseller. While earlier booster products generally supported the signals for a single operator, the latest commercial-grade products can handle multiple operators. To broaden the appeal of boosters, some vendors have introduced "networked" booster product that can extend coverage indoor with multiple remote radio units that coordinate with a central unit for boosting signals in a "smart" way to provide uniform coverage inside a building. By stacking these "central-remote" systems, these "smart booster" solution can extend booster coverage beyond the traditional booster coverage limit of 80-100K sq. foot .



Source: Nextivity

Figure 12. "Smart" Booster Architecture (Off-Air or Small Cell-Powered)

Summary of IBW Solutions and Market Fit

While the growing list of cellular in-building wireless solutions can theoretically scale up and down the required capacity handling and coverage (for some), we believe that each solution is targeted for certain target capacity and coverage "sweet spot" as illustrated below.

1. *Repeater + OTA (over the air)*: This solution is targeted for low-density venues typically less than 50K sq. foot. Based on "enterprise" grade boosters on the market such as Wilson Pro, Hi-Boost, SureCall, and others, depending on the configuration of outdoor donor antenna (directional or omni), the actual indoor coverage will vary depending on how near or far Macro towers are. Due to increasing utilization of Macro towers, we expect this type of solution will be less likely to be approved by the operators, especially in urban areas.

2. *Smart Booster + OTA / Small Cell*: This type of solution refers to active DAS hybrid solution such as Nextivity's QUATRA system in which four remote units are deployed in conjunction with a central unit that handles "active" RF distribution to the four remote units to increase SINR for more uniform coverage. By stacking multiple Smart Booster systems, this solution can cover much larger facilities, perhaps up to 500K sq. foot depending on in-building configuration and distance to Macro towers outside. For a low-capacity venue like a large warehouse, the "off-air" OTA option may be sufficient. For venues that require higher capacity handling, we believe an operator-approved signal source such as small cell would be a good alternative.

3. *Light DAS + OTA / Small Cell*: This solution is generally targeted for larger and complex indoor venues with relatively low capacity handling requirement (less user or cellular data traffic). A large and complex indoor configurations, we believe, will require more traditional DAS construction with a variety of remotes and cabling runs to optimize for performance. It is a matter of cost/performance tradeoff. Based on RF design requirements, one may decide to install a "Smart" Booster system with uniform placement of remote units vs. conducting a thorough RF planning and placing "Light DAS" nodes with possibly different cable runs. One centralized DAS headend for management and maintenance support may provide some advantages vs. managing multiple Boosters. Like the previous case, depending on the capacity requirement, both "off-air" and small cell options should be considered for signal source.

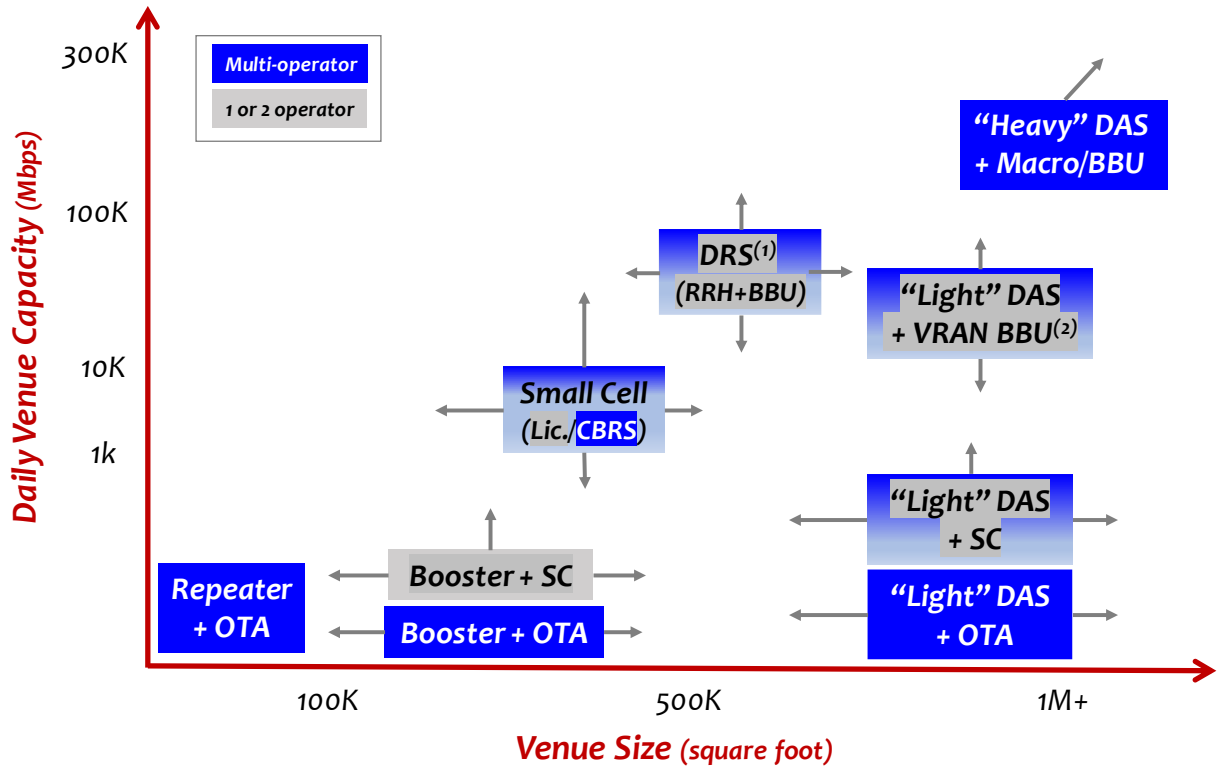
4. *Licensed Small Cells*: This solution is ideal for operator-specific deployments across different venue sizes and configurations. Since capacity handling is inherently built into the enterprise small cells, small cells can be placed in "hot spot" locations within venues to provide necessary capacity handling. For example, a convention center wing of a large hotel or a casino may be a good fit here. A downside, of course, is that multi-operator support requires separate operator-specific small cells to be deployed. While the coverage can be scalable depending on how many and where the small cells are deployed, we generally view the "sweet spot" for standalone integrated small cells in the range of 250K sq. foot.

5. *CBRS Small Cells*: This solution is a variation of the previous case except that the CBRS small cells has the potential to be a multi-operator solution if all major operators adopt CBRS as a mainstay operating band for their mobile services. While there is no guarantee that this will pan out, if all major operators adopt this approach, we believe this can provide a low-cost approach to solving the cellular in-building challenge for the industry.

6. Distributed Radio System (DRS): This solution is ideally suited for operators looking to leverage existing Macro infrastructure to extend coverage and capacity indoors. However, we believe this has some inherent business challenges for neutral host providers and venue owners. While this small cell-based solution provides scalable solution to extend coverage and capacity seamlessly from Macro to indoor venues, it is inherently tied to Tier 1 incumbent vendors' ecosystem of infrastructure products, starting with BBU. For indoor projects where operators are primary funders, this solution will likely be favored, assuming that venue owners and neutral host providers are okay with the possible "vendor lock-in" situations.

7. *Heavy DAS + BTS / BBU*: This classic DAS solution will remain the primary mainstay for very large, highly complex venues that require a "shared" infrastructure framework to support all major operators and large number of frequency bands. As operators

build out numbers of edge data centers with BBU pools, we expect many large public venues will be driven via BBU instead of on-premise base stations.



Source: Mobile Experts

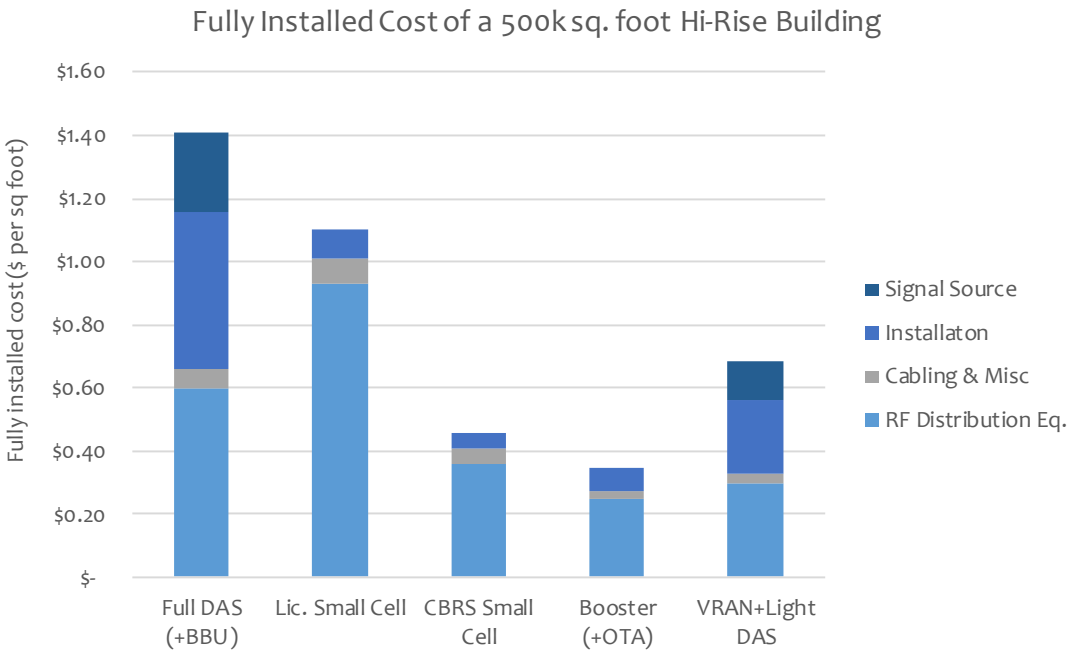
(1) Some DRS vendor solutions provide "multi-operator" support through same-vendor BBU or RF signal interfaces; however, its application is not widespread. Most are operator-specific DRS deployments.
(2) VRAN multi-operator capability depends on whether a VRAN gets carrier approval from all or select operators

Figure 13. Cellular IBW Solution Fit by Capacity and Coverage

Comparative Economics

It is difficult to make a direct comparison between the different cellular in-building wireless solutions as each is generally targeted for different segments. For example, while it is feasible to deploy a "full-blown" DAS system supporting all four major operators in the USA with eight different frequency bands across 3G and LTE with a macro base station as a signal source, such a system would be an "overkill" for a 500K sq. foot size hi-rise building with low capacity requirements, for example. Similarly, relying on CBRS small cells for a "multi-operator" coverage may not be feasible if not all operators support the band. Nor is the VRAN BBU combined with a "Light" DAS deployment (to selectively support a few operators) realistic if the VRAN BBU is not approved by the operators. Despite these "if's and but's," it is helpful to look at the initial CAPEX costs of the various solutions to see how compelling each are for the target vertical segments. Below shows the fully installed CAPEX

cost of supporting three operators for a 500K sq. foot commercial building with moderate capacity demands.



Note: Cost estimates based on three operator support.

Source: Mobile Experts

Figure 14. Comparative IBW Solution CAPEX Costs

To compare the "coverage" cost elements, one can exclude the signal source costs from the graphs. By our estimate, the total CAPEX cost for the *Heavy DAS + BBU* solution is roughly $1.40 per sq. foot to provide three-operator coverage. Excluding the signal source, the "coverage" cost comes to about $1.10. For the *Licensed Small Cell* case, the total CAPEX cost is $1.03 per sq. foot. (Since, it is difficult to extricate signal source from Small Cells, we can assume the coverage cost is the same.) With the *CBRS Small Cell*, assuming that the CBRS band is commonly shared or supported by all major operators, the total CAPEX cost comes to only $0.42 per sq. foot. The *Smart Booster + OTA* solution provides a slightly lower cost at $0.35 per sq. foot. However, it should be noted that the "off-air" OTA signal source may not be adequate in this particular case. Selecting the right in-building wireless solution is not necessarily based on lowest $ per sq. foot equation. The solution must meet all the requirements around multi-operator support, capacity, and coverage aspects in total.

4 CAPACITY REQUIREMENT ACROSS ENTERPRISE VERTICALS

In last year's report, Mobile Experts explored the *cost per square foot* metric for general in-building wireless solution categories (i.e., DAS, Small Cells, Booster, and Wi-Fi) across the different vertical industries. In that analysis, the capacity requirement across the different enterprise venues was not closely studied. As mentioned previously, the permutation of in-building wireless (IBW) solutions can vary depending on the types of "RF distribution" methods (i.e., Booster, DRS, "Heavy" or "Light" DAS) and "capacity" source (i.e., Off-air, Small Cell, Macro BTS, CRAN or VRAN BBU) employed. Since both the "RF distribution" and "Capacity source" methods can be independently scaled, it is helpful to understand the capacity requirement across the different enterprise verticals to help optimize the overall CAPEX cost, to cover and to serve, the different in-building cellular needs.

As explored in detail in our *2016 Enterprise Mobile Infrastructure* report, each industry vertical venue exhibits different cellular traffic usage. Moreover, varying space configurations, user/cellular traffic density, and sizes make for unique in-building wireless network implementations. For our analytical framework, average venue size along with user and wireless traffic profiles are factored into our calculation of capacity throughput requirement based on peak traffic profile at the different venue types.

Capacity Requirements of the Different Verticals

To calculate the peak capacity throughput density of a venue, wireless data usage per user (per visit) is determined. We then isolate cellular traffic usage by removing the portion of mobile traffic offloaded to Wi-Fi. Next, peak user density at the venue is determined, and this user density information is translated into cellular traffic density. Since not all users are expected to utilize the in-building wireless network all at the same time, the average venue traffic capacity required is calculated by taking the peak capacity throughput density multiplied by venue size divided by a "peak-to-average" ratio. For example, the peak-to-average ratio for the stadium case is assumed to be 10:1, meaning that on average, $1/10^{th}$ of the crowd at the stadium will be utilizing the in-building wireless network at the same time.

Applying the methodology as described above, the following capacity requirements for each of the enterprise venues are derived:

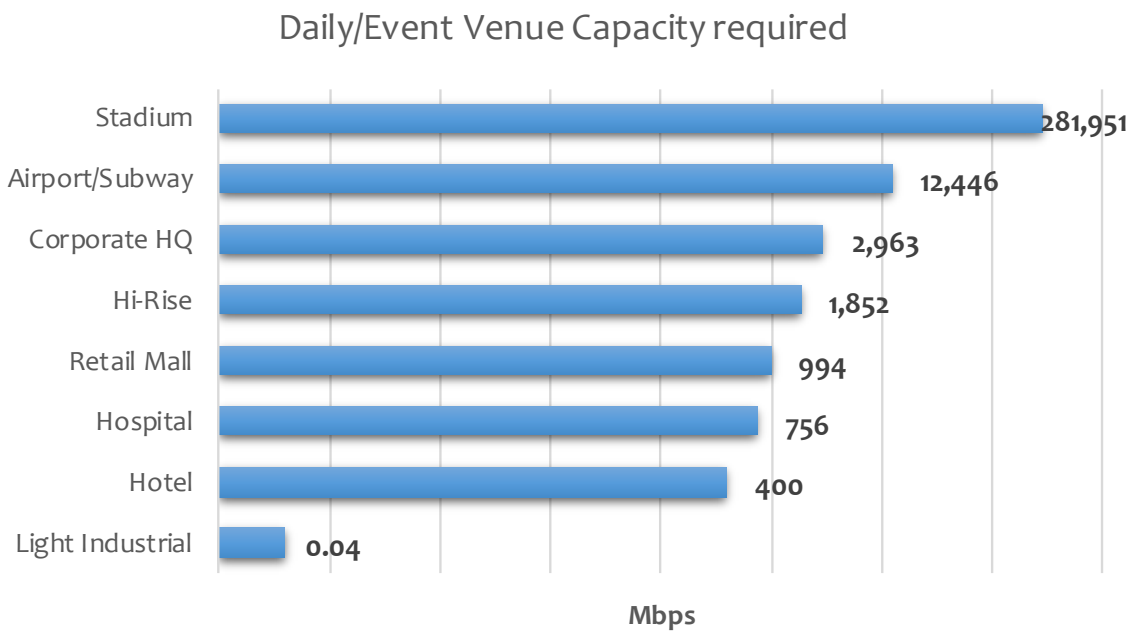
	Size (square foot)	Daily/Event Throughput Capacity (Mbps)	Relative (Stadium = 1)	Peak Throughput Density (Mbps/sq. foot)	Relative (Stadium = 1)
Stadium	1,750,000	**281,951**	1	**1.611**	1
Airport / Subway	630,000	**12,446**	~ $1/20^{th}$	**0.198**	~ $1/8^{th}$
Corp. HQ / Campus	1,000,000	**2,963**	~ $1/95^{th}$	**0.030**	~ $1/54^{th}$
Hi-rise Office	500,000	**1,852**	~ $1/150^{th}$	**0.037**	~ $1/44^{th}$
Retail Mall	900,000	**994**	~ $1/280^{th}$	**0.011**	~ $1/146^{th}$

Hospital	300,000	**756**	~ 1/370th	**0.025**	~ 1/64th
Hotel	150,000	**400**	~ 1/700th	**0.027**	~ 1/60th
Light Industrial	200,000	**0.04**	~ 1/7,000,000th	**0.000002**	~ 1/800,000th

Source: Mobile Experts

Figure 15. Capacity Requirements across Enterprise Venues

Ranking the average daily/event capacity requirements across the different venues, it is not surprising to see that Stadium ranks at the top. With major events like the Super Bowl drawing 50+ TB of cellular traffic as reported at the most recent Super Bowl, the traffic density at these major public venues is extreme, to say the least. With the average venue capacity reaching close to 300,000 Mbps, it is surprising to see DAS implementations with 100's of sectors to accommodate the growing traffic at major stadiums. Airport is another major venue where cellular traffic demand is growing. With unlimited data plans pervasive in the marketplace, business travelers are increasingly relying on cellular networks for mobile broadband access. At the far end of the spectrum, light industrial facilities like warehouses require very little capacity.



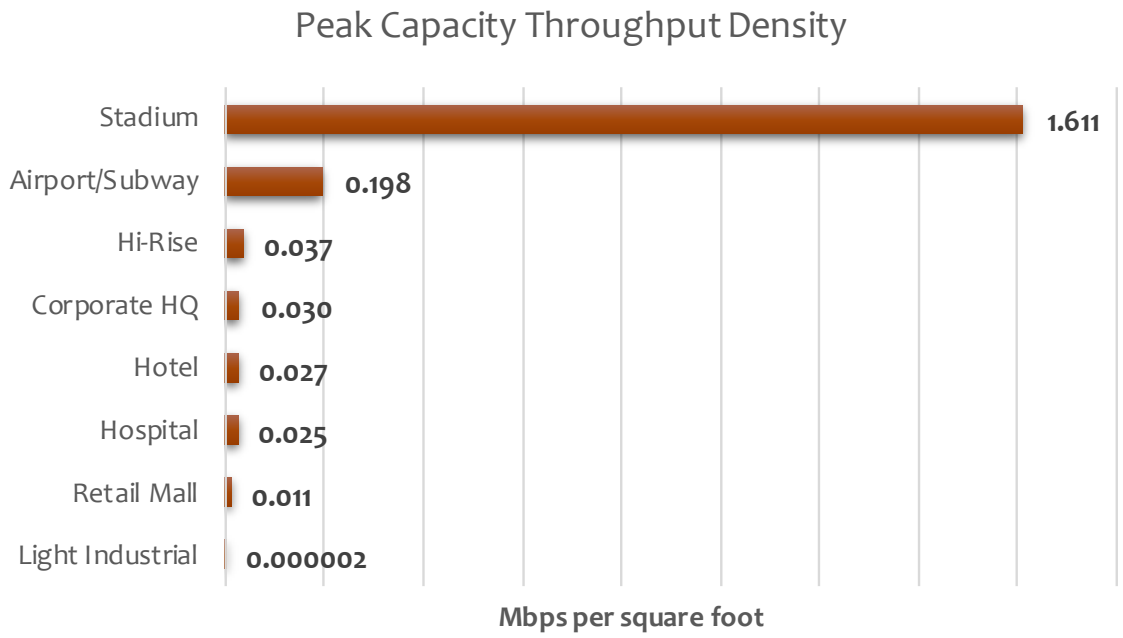
Note: Logarithmic scale

Source: Mobile Experts

Figure 16. Daily / Event Venue Capacity Required (highest to lowest)

Capacity (Throughput) Density

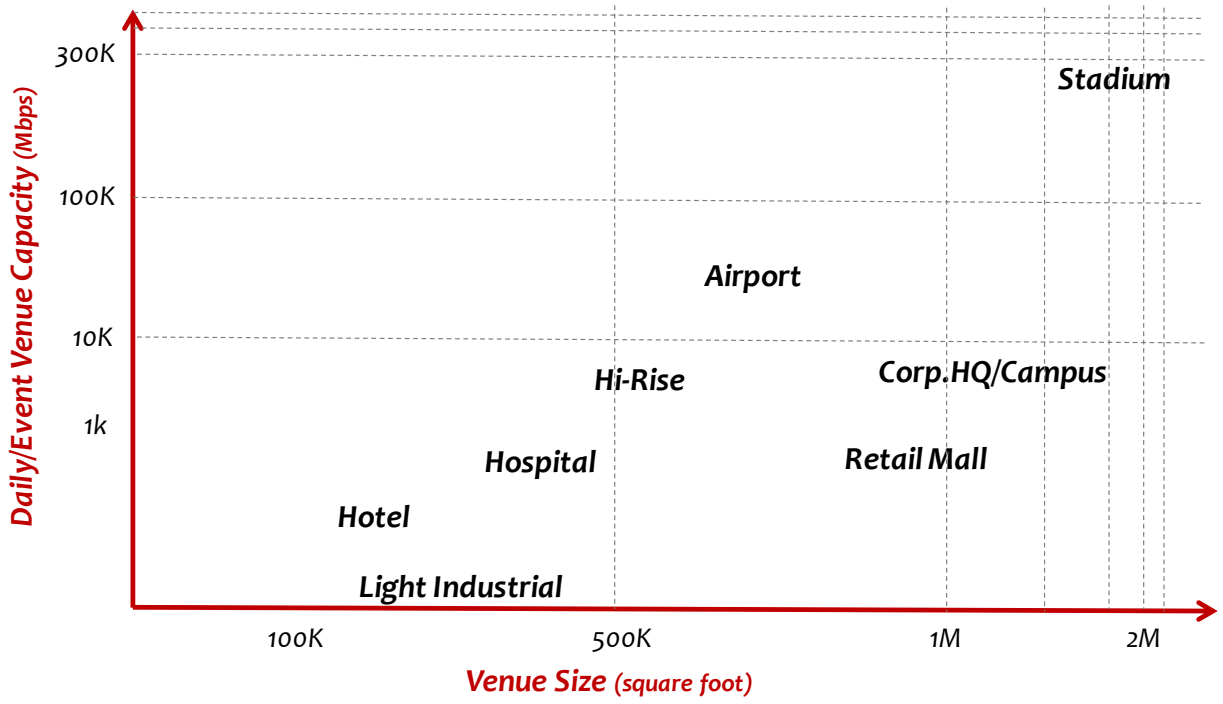
The capacity throughput density in terms of Mbps per sq. foot closely mirror that of the average capacity required at each venue type. Despite the relatively large size (close to 2M square foot at major stadiums in the USA), the capacity throughput density at a stadium is still the largest at around 1.6 Mbps per sq. foot. Although the average daily capacity consumed at a retail mall is 2.5x larger than a "mid-size" hotel, in terms of capacity density (Mbps per sq. foot), a hotel is higher than a retail mall. This is simply due to the fact that a large retail mall is about 6x the size of a mid-size hotel in our modeling.



Source: Mobile Experts

Figure 17. Capacity Throughput Density across Enterprise Venues (highest to lowest)

The following chart depicts the average capacity required at a venue vs. average size of the different enterprise verticals. From this chart, one can generally surmise that smaller spaces with low capacity requirements (i.e., enterprise vertical venues in the lower left corner of the below chart) may be addressed through "low-capacity, small-coverage" solutions like boosters or small cells. For very large spaces with ultra-high capacity, density requirements will require "high-capacity, large-coverage" solutions like traditional DAS solutions with Macro BBU as signal source to provide very high-capacity handling capabilities.



Source: Mobile Experts

Figure 18. Enterprise Venues by Size and Capacity Required

5 CELLULAR IN-BUILDING SOLUTION FIT BY CAPACITY

In last year's *Enterprise Mobile Infrastructure* report, we studied relative costs and other decision criteria, such as wireless link quality of service, ecosystem, and multi-operator feature, to identify general product fit of traditional cellular in-building wireless (IBW) solutions, including DAS, small cells, and repeaters. Based on that analysis, we concluded that DAS is generally good fit for large, public venues like stadiums and airports, and repeaters are good for low-density spaces like warehouses. Meanwhile, we concluded that small cells, especially CBRS neutral host variety, can be potentially effective solution that can handle high-traffic scenarios for single-operator scenarios, and potentially multi-operator, with CBRS.

	DAS	Small Cells (DRS/RRH)	CBRS Small Cell	Repeater	Carrier Wi-Fi
Stadiums					data offload
Airports / Subways					data offload
Hotels				small hotels	data offload
Hospitals				rural	data offload
Retail Malls					data offload
Multi-tenant Hi-Rise Buildings					data offload
Corp. HQ / Campus		single operator			data offload
Light Industrial					data offload

Source: Mobile Experts

Note: Color coding indicates product 'fit' against decision criteria of each vertical industry… (GREEN – best fit; YELLOW – possible fit; RED – bad match; LIGHT GREEN – Wi-Fi can provide data offload but cannot provide seamless voice service)

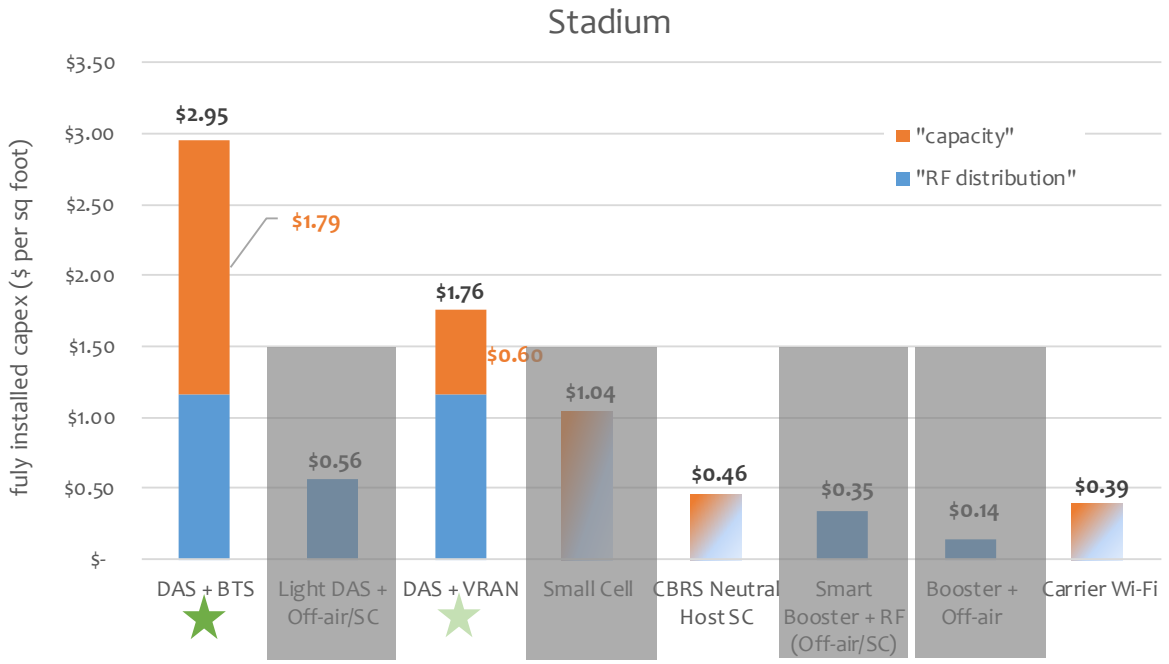
Figure 19. Cellular IBW Product Fit across Verticals based on Qualitative Assessment

In this year's report, we take a closer look to see what specific IBW solution would be most appropriate based on capacity requirements of each of the vertical industry venues.

Stadiums

Stadiums represent the most challenging case for cellular in-building wireless deployment. Stadiums are large (closer to 2M square foot in area coverage), and cellular traffic usage is generally very high. For example, at the most recent Super Bowl at the US Bank Stadium in Minneapolis, the three major carriers reported over 50 TB of cellular traffic usage in and around the stadium. With this level of traffic, any "off-air" solutions with Booster is a non-starter. Moreover, as a major public venue, an in-building solution must be able to accommodate multi-operator capability, which is challenging with Small Cell solutions.

While neutral-host CBRS small cells may be possible, it will likely be used as an adjunct solution like Wi-Fi as a data-offload network.



Source: Mobile Experts

Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost. The "Off-Air" solutions aren't feasible for stadium deployment as traffic density is too large; hence, they are blacked out. Moreover, the licensed Small Cell case is not feasible as stadium deployment requires multi-operator support. The capacity cost is provisioned based on cellular traffic observed at the most recent Super Bowl.

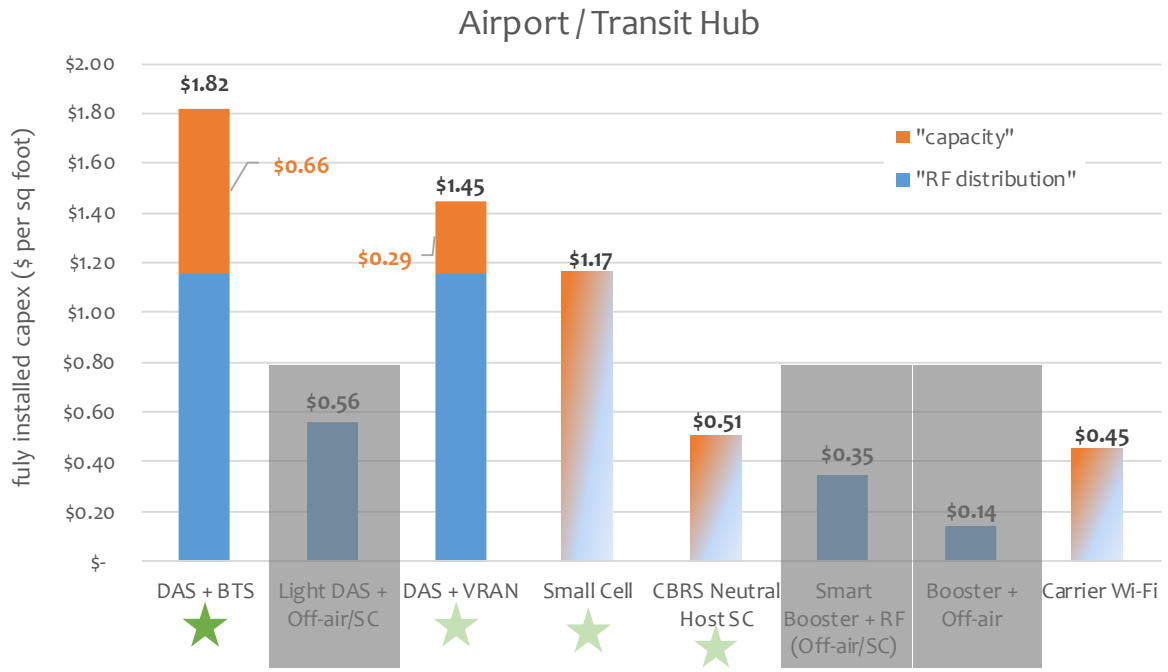
Figure 20. Total CAPEX (fully installed) cost of IBW deployment at a Stadium

It should be noted that the "RF distribution" cost pertains to the fully installed CAPEX cost of deploying "Heavy" DAS with three-operator support with multiple frequency bands for each operator. To provision for a very heavy traffic handling, a majority of CAPEX cost is for the Macro BTS signal source. While Virtualized RAN (VRAN) promises a significant cost savings by virtualizing baseband running on commercial off-the-shelf (COTS) servers, its adoption hinges heavily upon product maturity and significant operator support. For this reason, we believe the traditional "Heavy DAS + BTS/BBU" implementation is most suitable for the Stadium use case today. It should be noted that the 1/7th cost differential between Macro BBU from incumbent vendors and VRAN running on COTS server is largely based on VRAN vendors' claims. Without meaningful market uptake of VRAN implementations at scale, it is hard to accurately estimate the VRAN costing at this early stage. The VRAN cost estimates in our analysis should be considered as general "ballpark" figures at this point.

(We believe VRAN solutions must have disruptive pricing or significant cost-saving features to perk the interests of operators. Without these promises, it would be very difficult to unseat the major vendors' incumbent positions in operators' RAN networks. While we remain cautious that new entrant's VRAN implementations can really achieve the "1/7th cost savings" as modeled in our analysis, we are hopeful that some major operators will be willing to give this a try for in-building wireless applications.)

Airports and Transit Hubs

After stadiums, airport and transportation hubs are the most demanding enterprise venues in terms of coverage and capacity requirements. Moreover, these are highly trafficked public venues that require multi-operator support. While an "off-air" solution like booster is a natural multi-operator solution, it does not come close to meeting the high capacity requirement, which is, on average, 12,500 Mbps of average daily throughput capacity. In terms of peak throughput density, it is 0.198 Mbps per sq foot or 1/8th of a NFL stadium capacity requirement.



Source: Mobile Experts

Note: "Heavy" DAS deployment for 3-operator support. The "Off-Air" solutions aren't feasible for stadium deployment as traffic density is too large; hence, they are blacked out.

Figure 21. Total CAPEX (fully installed) cost of IBW deployment at an Airport

With relatively high coverage and capacity requirements, airport and large transportation hubs are best addressed through "Heavy" DAS plus macro base station or BBU implementation for a full multi-operator support. While it is theoretically possible to leverage licensed small cells, placing multiple small cells – one for each operator – at each remote location may become burdensome in terms of real estate, installation, and on-going maintenance. Similarly, while CBRS neutral host small cells are economical in meeting the multi-operator requirement, they are still nascent and will take some time until the critical mass of CBRS-capable handsets become more mainstream. For these reasons, we believe the traditional DAS plus BBU, while most expensive, is best suited for this vertical segment in the near term. It should be noted, however, that some smaller airport and transportation hubs (less than 400-500K square feet) may opt for licensed or neutral host (CBRS) small cells to target specific "hotspot" areas where indoor coverage is seriously lacking.

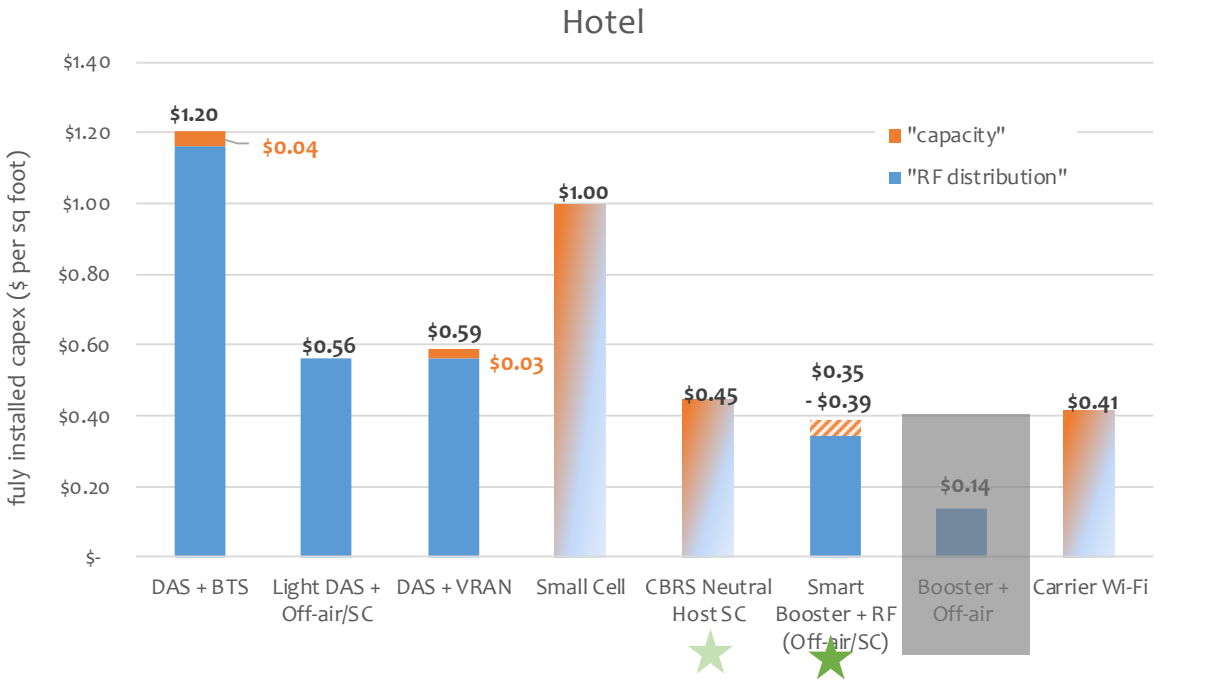
Furthermore, while the VRAN BBU combination with DAS implementation potentially yields a much cheaper solution, it will require operator approvals which can be lengthy.[2] Also, in certain instances where a "full" multi-operator requirement is not necessary, a DAS plus BBU implementation can be cost-optimized through "Light" DAS implementation whereby certain frequency bands and strategic operators are supported through operator-approved small cells as a signal source to cost-optimize initial CAPEX investments.

Hotels

Hotels brings unique challenges for a cellular IBW solution. Depending on the class and size of a hotel, the cellular traffic pattern and usage will vary, so it is hard to prescribe a "best fit" IBW solution to this vertical segment. In this report, we have modeled a "mid-size" hotel of 150K square foot size venue. With that said, we can disregard the traditional booster solution as this venue size would be too large for a booster solution to provide uniform coverage throughout. With a key focus on capacity requirement, it should be said that Hotels of this type generally do not generate or consume that much traffic. Based on our estimate of 400 Mbps of daily average use, hotels are one of the less-demanding facilities in terms of capacity.

While it is debatable how willing operators are to allow "off-air" solutions, we believe that the "Smart" Booster solution with a donor antenna is a cost-effective, multi-operator solution for low-to-mid size hotels. If operators are reluctant to allow access to Macro capacity outside, a "Smart" Booster solution can be driven with operator-approved small cells as a signal source. Alternatively, once enough handsets with CBRS-band support become more widely available, and operators begin to leverage CBRS band more heavily, we believe CBRS neutral host small cells can become scalable IBW solution.

[2] The viability of VRAN BBU as a signal source for multi-operator support implies that the VRAN solution needs to be approved by each operator. We believe this process can be one to two years for each operator.



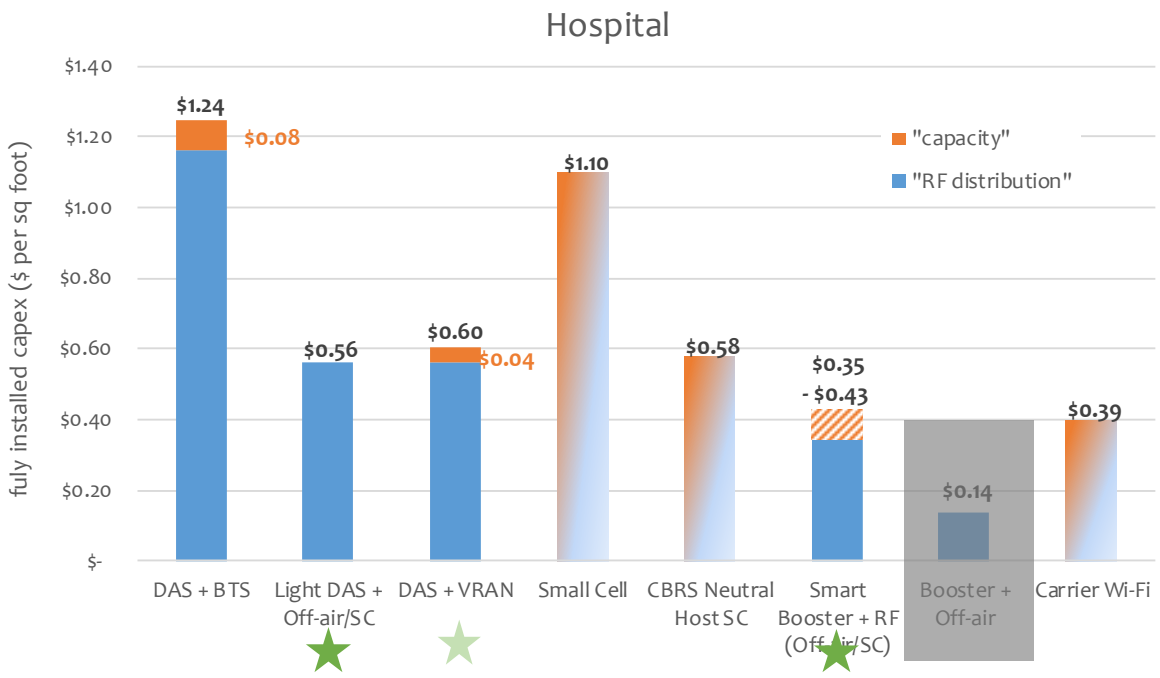
Source: Mobile Experts

Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost.

Figure 22. Total CAPEX (fully installed) cost of IBW deployment at a Hotel

Hospitals

As noted in the previous section, hospitals are relatively low-capacity, mid-size spaces. At the same time, mobile communication is becoming integral part of workflows at these complex venues. Doctors, nurses, first-responders, and administrators are increasingly relying on mobile communication via their personal devices to take care of urgent tasks. In this dynamic environment, having reliable wireless links is often life-critical, and that means that cellular in-building solutions are becoming more and more critical. With most mid-size hospitals ranging around 300K square feet, and hospital staff often on the same carrier plans, "Light" DAS implementation supporting top two operators may be sufficient to provide coverage. Moreover, it is also feasible to use multiple "Smart" Booster systems to cover bigger spaces (up to 500K square feet) while providing uniform coverage. With the capacity throughput density on the lower rung of spectrum, it may be possible to use "Off-air" solution in suburban or rural areas where Macro utilization is often low. For hospitals in urban settings, where "spare" Macro capacity is scarce, small cells can be used as a local signal source for capacity handling.



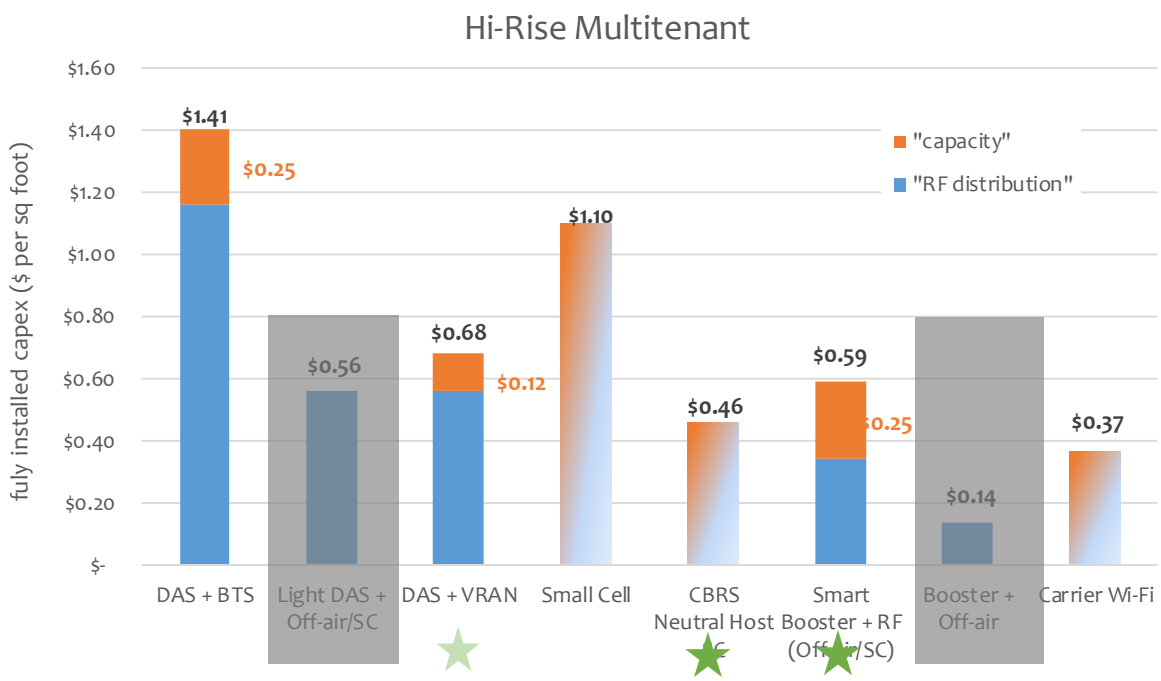
Source: Mobile Experts

Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost.

Figure 23. Total CAPEX (fully installed) cost of IBW deployment at a Hospital

Multi-Tenant Hi-Rise Buildings

With average venue size of 500K square feet and relatively high capacity requirement of 0.037 Mbps per square foot, the "off-air" IBW solutions like standalone boosters are not suitable for coverage throughout a hi-rise multitenant building. At the same time, a full-blown "Heavy" DAS plus on-premise macro base station or BBU or multiple licensed small cells for a multi-operator support would be overkill. Here, a "Smart" Booster solution may provide a good economical solution since each system with multiple radio units can be compartmentalized to provide coverage/capacity solution per floor or a tenant occupying a section of a floor. Also, in case that a tenant has a carrier contract with a certain operator, a small cell approved by that operator can be used as a local signal source to drive the booster system, thus providing a self-contained coverage/capacity solution. Another natural in-building solution is the CBRS neutral host small cells (assuming that multiple operators adopt the CBRS band for mobile broadband services).



Source: Mobile Experts

Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost.

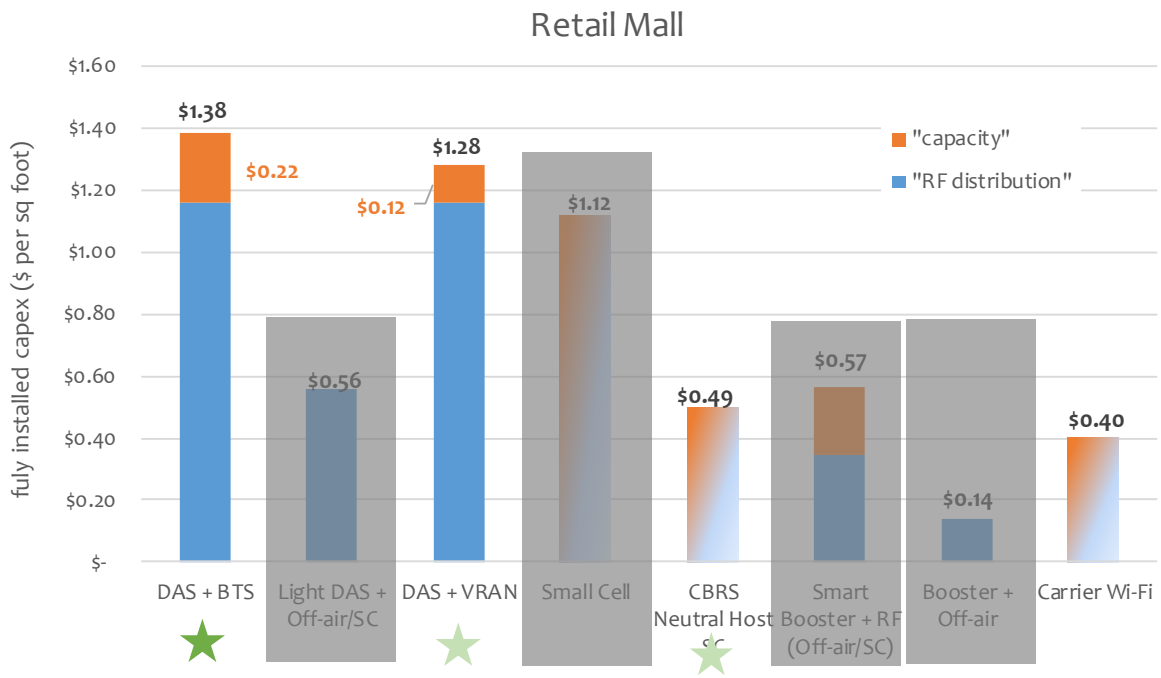
Figure 24. Total CAPEX (fully installed) cost of IBW deployment at a Hi-Rise

Retail Shopping Malls

While the capacity requirement is relatively low, retail malls are challenging spaces for cellular in-building wireless solutions for two key reasons. Retail malls are major public venues, and a major mall can cover a relatively large space -- around 1M square feet. To provide a truly multi-operator coverage, a traditional "Heavy" DAS implementation may be required to provide coverage across all major operators and multiple frequency bands for broad coverage across different services and devices. Since the capacity requirement is relatively low, the majority of fully installed CAPEX cost is for DAS coverage.

While the most economical solution is a neutral host small cell implementation via CBRS, this particular IBW solution requires operator adoption of CBRS adoption into its services and corresponding support on mainstream handsets. Mobile Experts believes that the critical mass of CBRS handset installed base will take some years to develop. Hence, the most viable solution today is the traditional DAS implementation. It should be noted while the DAS + VRAN implementation provides lower "capacity" CAPEX costing, the relative merit of this solution is not that significant in this case since the overall CAPEX is really driven by the "coverage" cost associated with DAS implementation. We expect very large venues with

low capacity requirements will generally adopt traditional signal sources of Macro BBU, operator-approved small cells, or "Off-air" via donor antenna.



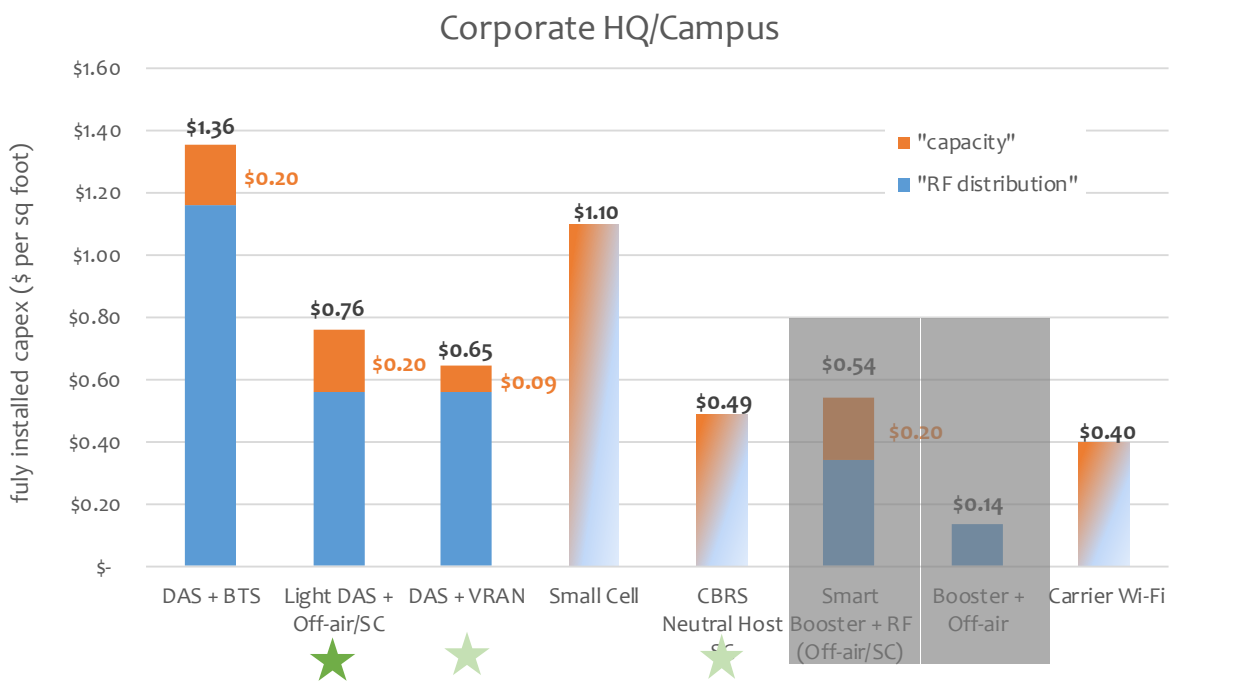
Source: Mobile Experts

Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost.

Figure 25. Total CAPEX (fully installed) cost of IBW deployment at a Hi-Rise

Corporate Office / Campus

Corporate office or campus environments are typically large venues with similar capacity density requirements as Hi-Rise multitenant venues. Unlike other large spaces like Retail Malls, corporate office/campus environment do not necessarily need to fulfill multi-operator support, since most large corporations have enterprise carrier account with one or possibly two large operators. Because of this, "Heavy" DAS implementation is not necessary in all cases. "Light" DAS coverage supporting one or two operator frequency bands would be sufficient to provide coverage for most of the employee base using company-provided mobile phones. Based on fully installed CAPEX cost estimates and capacity requirement at a corporate campus, Mobile Experts believes that a "Light" DAS plus Small Cells as a signal source would yield an economical solution at around $0.75 per square foot.



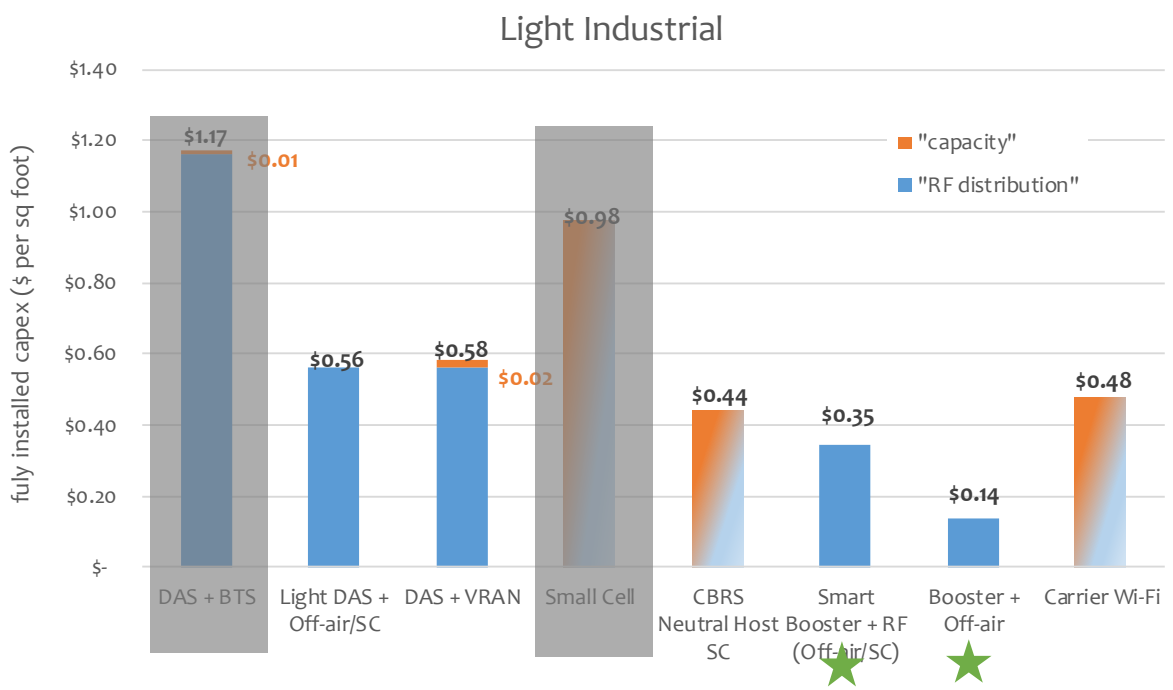
Source: Mobile Experts

Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost.

Figure 26. Total CAPEX (fully installed) cost of IBW deployment at a Corporate HQ/Campus

Light Industrial Buildings

Light Industrial venues like warehouses are perfect fit for the "off-air" in-building wireless solutions like boosters since cellular traffic demand is extremely low. Moreover, the inherent "multi-operator" nature of "off-air" solutions make them ideal to support multiple operators economically. Industrial booster products from key vendors like Wilson Pro, Surecall, HiBoost, and others promote high-end units that can cover up to 80-100K square foot. While actual coverage will vary depending on how far the macro towers are from a donor antenna, it is likely that smaller light industrial buildings (less than 100K square feet) can be covered through traditional bi-directional amplifier (BDA) boosters. Meanwhile, some "smart" boosters that take advantage of active DAS principles by networking multiple remote radio units to a central unit (e.g., Nextivity's QUATRA product) can cover larger spaces by "stacking up" multiple central-remote unit systems together to extend coverage. We are hearing some system integrators deploying "smart" boosters in 500K square foot facilities.



Source: Mobile Experts

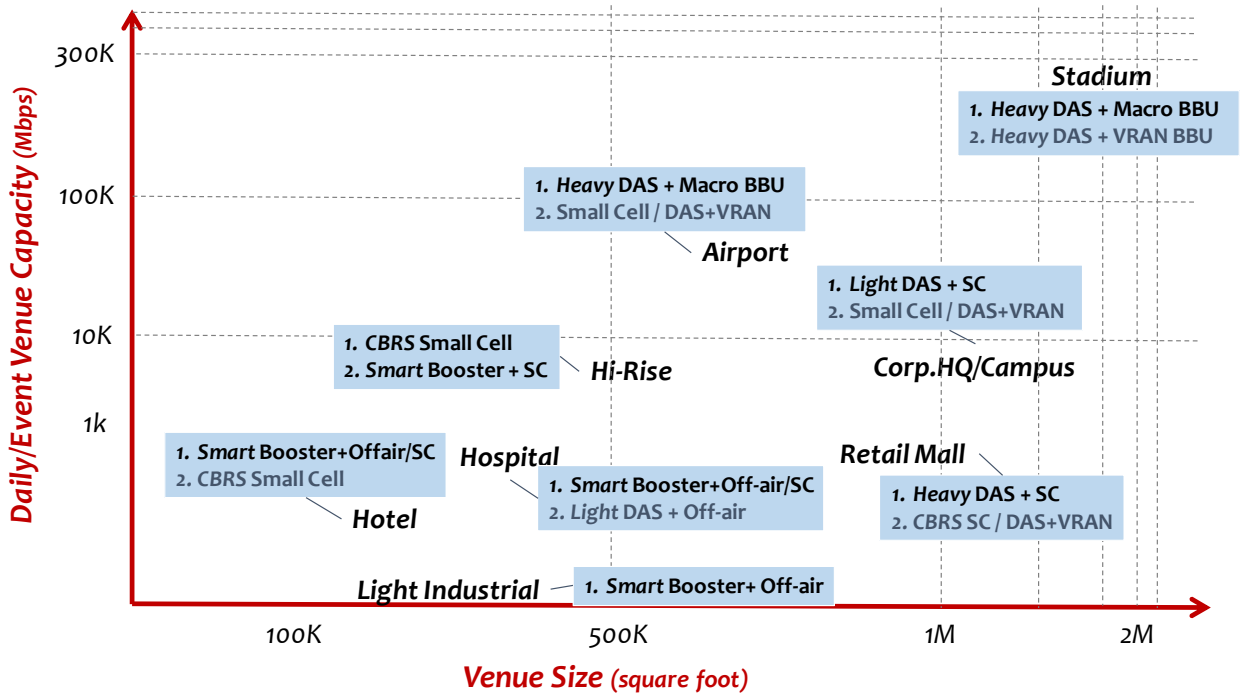
Note: CAPEX cost estimates based on 3-operator support, except for Light DAS case where limited number of frequency bands for up to two operators are supported to lessen the active DAS equipment cost. The Heavy DAS + BTS and Small Cell options are blacked out as they are overly expensive solutions for the requirements of the venue.

Figure 27. Total CAPEX (fully installed) cost of IBW deployment at a Light Industrial Building

While all other high-end IBW solutions that can extend coverage and capacity systems including DAS and Small Cell solutions are certainly applicable, they are "overkill" for light industrial venues that do not have extensive coverage and capacity requirements. We estimate that an average light industrial venue only requires about 40 kbps of average capacity. In terms of traffic density (Mbps per sq. foot), the capacity required for an average Light Industrial venue is about 1/300th of that of a Stadium in the USA.

Cellular IBW Solutions for Verticals

Based on fully installed CAPEX estimates of various in-building wireless solutions based on capacity requirements, we come to the following general recommendation of primary and alternative IBW solution offering per each enterprise venue.



Note: "DAS + VRAN BBU" as a secondary recommendations for many of the verticals is largely based on our cautious view of operator adoption. It provides a compelling lower CAPEX cost profile. Assuming it is widely adopted by operators, it would certainly become primary recommendation in many cases.

Source: Mobile Experts

Figure 28. IBW Solution Recommendations for Enterprise Venue Types

6 REGIONAL OUTLOOK

As noted in last year's report, multiple factors, such as cultural, economic, ecosystem, and regulatory policy, across the different regions and countries impact business models and the different mobile infrastructure investment decisions. Enterprises in China and India behave very differently than those in the USA and Europe. One of the fundamental differences centers around the business norm of who is responsible for indoor mobile coverage and services and who is ultimately responsible for paying for cellular infrastructure indoors.

Here are some examples of factors that influence business model development and likely choice for enterprise mobile infrastructure:

1. Economic/Political System: Enterprises based in capitalist countries will invest more readily in wireless equipment. Enterprises in communist countries, or any country with a top-down political structure, will generally rely on the mobile operators to take care of in-building coverage. In other words, enterprises that feel free to invest in telecom hardware will do so.

2. Ecosystem Maturity: North America and the UK have generally mature ecosystems of system integrators and neutral host providers for DAS and Wi-Fi installations. Hundreds of small, local companies support IT/telecom projects for companies and large DAS and Small Cell infrastructure projects for operators. Therefore, in the United States and the UK, we see quick development of an enterprise mobile infrastructure market. Other countries in Latin America, Eastern Europe, India, and Asia do not have rich ecosystems of system integrators and infrastructure companies at local levels to address specific enterprise needs across geographies and vertical industries.

3. Regulatory Regime: Many Western countries have deregulated the telecom market to separate wireline and wireless business groups. This means that in some countries, the mobile operator does not have access to many fiber assets. For example, we see a mix of wireless-only, wireline-only, and some fixed/mobile operators in the USA and Europe. Mobile operators in the USA look to wireline service providers for fiber backhaul. In contrast, many mobile operators in China, Japan, and Korea also have significant fiber assets. With fixed line assets at their disposal, with low internal transfer pricing, these operators have been early proponents of CRAN architecture using Remote Radio Head designs which use high-bandwidth CPRI interfaces.

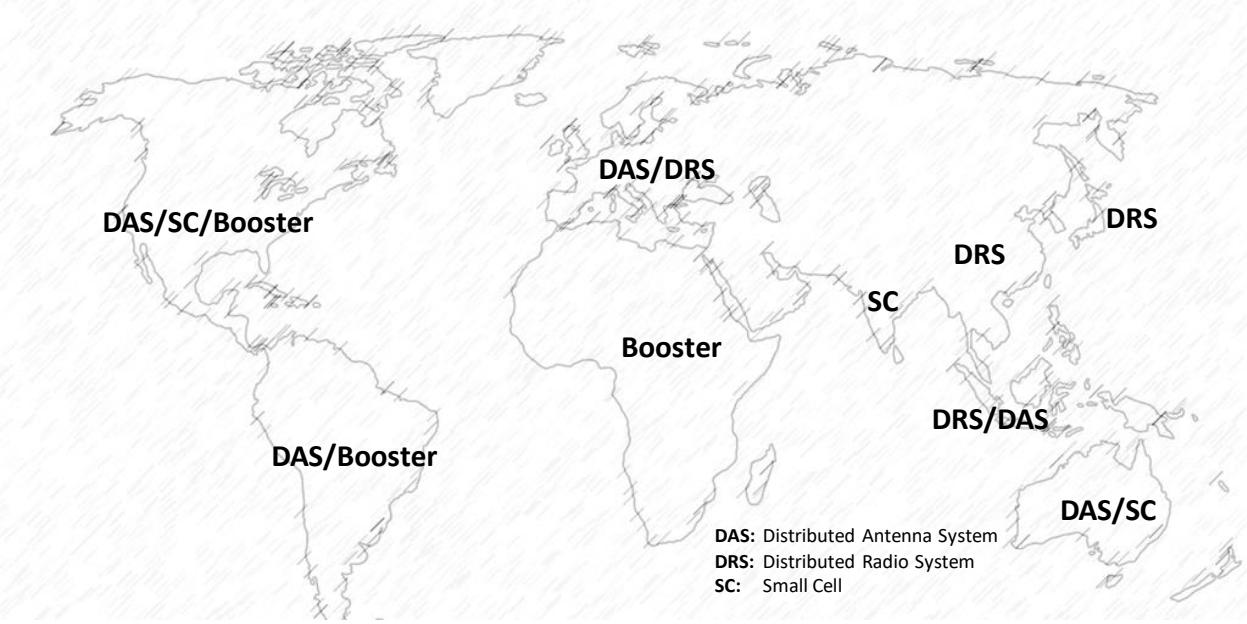
4. Spectrum: Countries that have released huge blocks of spectrum are generally more focused on deployment of macro base stations with spectrum overlay to more efficiently deploy capacity. However, for operators that are more spectrum-constrained will need to source in-building solutions to more aggressively to expand

mobile coverage, and to increase data capacity indoors to address the rising mobile traffic growth. This is necessary not only to meet the demand locally but also to relieve strain on macro networks which is more critical in consumer perception of mobile service quality.

5. Industry Structure and Competition: Countries that have multiple strong mobile operators (i.e., with substantial share of subscribers) tend to move toward DAS solutions in key in-building mobile infrastructure projects such as stadiums and airports. To meet this growing need The USA and UK have highly developed DAS ecosystems because of the relatively even market share of multiple players in these countries. In Mexico, as a counter-example, Telcel dominates with 70% of the subscribers, so DAS project decisions are dependent upon the support of Telcel to be viable.

6. Competition and Profitability: The Average Revenue Per User is a key metric. Operators with high ARPU will naturally invest more in an in-building project to ensure that customers can keep generating revenue inside the building. Operators with low ARPU simply will not invest. Some operators are starting to use a metric such as "ARPU per square foot" to understand the potential ROI for investing in a building.

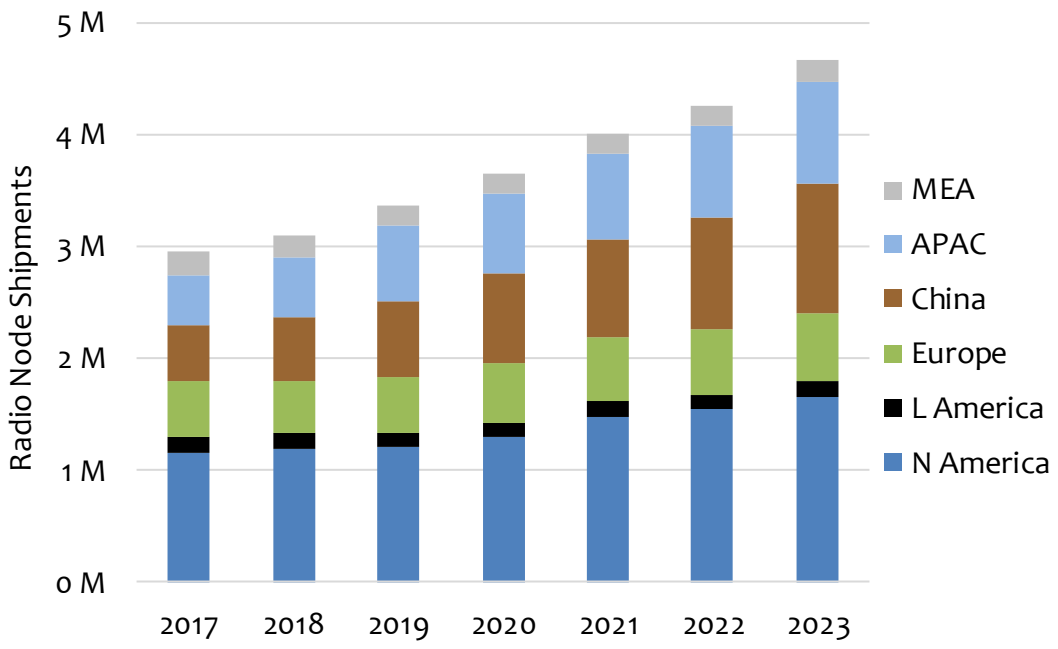
7. Enterprise IT Market: One of the key dynamics that drive the enterprise mobile infrastructure market is the maturity of enterprise IT market overall. Many enterprises in Western countries have traditionally relied on their own IT staffs and ecosystem of networking suppliers like Cisco to develop IT-centric products for in-building telecom needs. For example, Wi-Fi is a good example of enterprise-centric wireless technology that has served the enterprise market very well over the past decade. In strong enterprise IT markets like the USA and Europe where many of the top global companies are based, enterprises will likely also expect mobile infrastructure products and solutions that can meet enterprise-specific and vertical industry needs in each of the regions. Depending on specific vertical industry requirements, enterprises and system integrators are deploying a combination of DAS, small cells, and booster solutions in conjunction with different signal source types including off-air, small cells, and traditional macro BBU.



Source: Mobile Experts

Figure 29. Direction of in-building investment in world regions

In summary, these factors shape the use of in-building mobile infrastructure. Overall, some regions will support ongoing evolution of multi-operator technologies (such as DAS), while other regions are more suited to operator-led projects using small cell/RRH based DRS systems like Ericsson's Radio Dot and Huawei's LampSite. Extremely low-cost markets with that remain mostly coverage-driven will be fine with tapping the outdoor macro capacity via low-cost booster/repeater solutions. The complex indoor environments with high capacity and multi-operator requirements will increasingly rely on a combination of DAS, small cell, and "smart" booster to increase coverage and leverage different signal sources depending on the level of capacity handling required.



Source: Mobile Experts

Chart 2: Enterprise In-Building Mobile Infrastructure Shipments, by region

While the growth in DAS market has flatlined, the North American market still represents more than 40% of the overall in-building wireless market in terms of end radio or antenna node shipments. While major large venue projects like stadiums are harder to come by, the enterprise mobile infrastructure market is fueled by system upgrades and small cell and booster implementations at smaller venues. Large numbers of regional system integrators are supplementing traditional DAS projects with cheaper system alternatives to tackle a big pool of smaller venue projects. Mobile Experts believes that North America will be, by far, the biggest market for traditional DAS deployments due a well-established ecosystem of vendors and system integrators and a general cultural willingness to try something new.

In Latin America, coverage issues still count more heavily than in North America, so economical solutions that address coverage find a good traction here. Passive DAS systems and some booster systems are used in Latin America to this day. Some Latin American countries are dominated by one or two mobile operators, so single-operator products such as small cells may be appropriate in some cases. However, the small cell deployments will be sporadic initially until their adoption is more well established in North America, and to a lesser degree, in Europe. The ecosystem of system integrators and installers is relatively weak in Latin America, but it is growing. As key Latin American cities reach high traffic density (Sao Paolo, Mexico City, Buenos Aires), we expect to see a heavier use of small cell solutions.

Europe, especially more developed areas in the Western and Nordic regions, is likely to follow the US model, with a slight delay in enterprise channel adoption and ecosystem maturity. Southern and Eastern Europe generally invest less simply due the macroeconomic conditions. Enterprise investments and business model development in the more "CAPEX rich" northern area will eventually lead to similar investment in the south and east. In most European countries, at least two to three, sometimes four, operators compete aggressively, so multi-operator solutions will be important. However, some enterprises are willing to adopt solutions that only support top two operators to reduce the overall infrastructure cost.[3] While we expect to see more direct investment by the enterprises, the main "drag" in market adoption continues to be mobile operators' naturally conservative approach to really open up the market for greater in-building wireless solutions.

In China, all three major operators are state-owned, and technology and market decisions are sometimes driven from the top. Theoretically, one would think that common ownership would lead to friendly relations between the companies, but in fact, these companies compete aggressively. For in-building projects, the three operators work independently in most cases. It is not that uncommon to see multiple in-building solutions co-located in a same facility. While traditional DAS systems based on simple bi-directional amplifiers have been deployed for single-operator applications in the past, operators are mandating "digital indoor" strategy foregoing cheaper passive DAS systems to digital ones like Distributed Radio Systems (DRS) like Huawei's LampSite and ZTE's Qcell. Shopping malls, airports, and other major public buildings are currently adopting this small cell/RRH-based systems. This "digital indoor" trend has impacted domestic manufacturers of traditional DAS and booster systems. Culturally, enterprises are not likely to invest heavily in the hardware in China, because the operators make direct investment in indoor systems. The operator investments are in some ways a political government stimulus -- making the need for enterprise investment doubtful.

In Asia (excluding China), enterprise investment is a stronger possibility. In the Southeast Asia, the Philippines, Indonesia, Malaysia, and India in particular, poor coverage and capacity for 3G and LTE systems indoors is driving some companies to invest in small cells and DRS systems. Passive DAS systems are also used today as they offer cheaper alternative, but some are following the DRS trend happening in China. In Japan and Korea, operators have done an excellent job in covering most urban buildings. With ample supply and cheap access to fiber, Remote Radio Heads (RRH) small cell and DRS approach is becoming popular. Like China, the Japanese and Korean operators typically make direct investment in indoor systems.

In the Middle East and Africa, there are two outcomes. Rich economies such as UAE, Israel, and Saudi Arabia will have urban capacity issues, and concentration of market share drives enterprises to invest in single-operator solutions. On the other hand, poor economies such

[3] We find this same trend in other regions as well as enterprise-direct investments require more cost-conscious deployments.

as Ethiopia, Libya, and Pakistan are less likely to see significant in-building investment, either by the operator or the enterprise. Mining operations, oil/gas facilities, and other major economic centers are an exception as large multinational industrial companies are rich enough to fund these projects, especially if IoT applications become critical to operations.

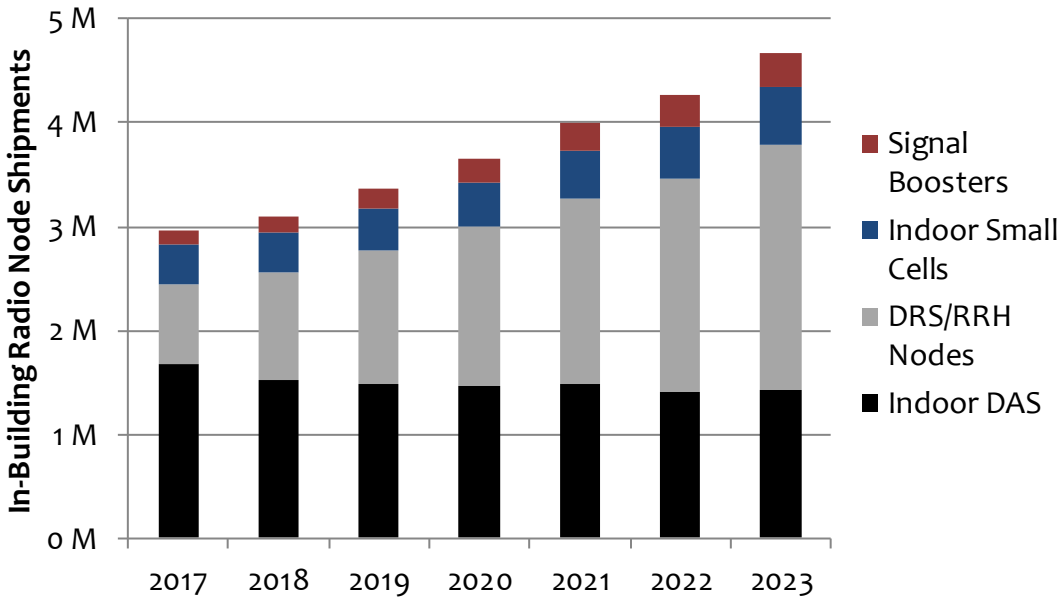
7 EQUIPMENT FORECAST

While the market for macro base stations transitions from 4G to 5G in many of the developed markets in North America, Asia, Europe, the market for in-building mobile infrastructure continues to grow steadily. A simple fact is that the need for in-building mobile infrastructure will remain as long as the mobile data usage grows. Both operators and enterprises will invest in mobile infrastructure hardware to outfit the buildings that they care about. For example, the operators are incentivized to invest in major public places like stadiums to tout their fast services to prevent churn, and major enterprises are forced to invest in indoor mobile infrastructure to provide seamless mobile services for tenants and employees who increasingly rely on their mobile devices for work communication and enterprise applications.

This section provides a general overview of the shipment trends for each equipment type. A more thorough review of pricing, revenue, and market shares can be found in the Mobile Experts market studies for individual technologies, including *Small Cells*, *DAS*, and *Carrier Wi-Fi and LTE-U*.

Shipment Outlook

While DAS is the largest product segment of enterprise in-building mobile infrastructure deployments today (and revenue share at close to 60% of total enterprise mobile infrastructure market), the future growth will come from Small Cells. The strongest element within the small cell segment will be the Distributed Radio Systems (DRS) systems that allow scalable deployment for single-operator or multi-operator (via RF-to-CPRI interface) deployments. Most product segments will grow over the next few years – some faster than others.



Note: includes enterprise-driven/targeted in-building radio nodes by both operators and enterprises

Source: Mobile Experts

Chart 3: In-Building Radio Node Shipments, DAS vs. Small Cell vs. Repeater, 2017-2023

DAS is a mature product segment and represents the largest in-building wireless solution segment today. It is largely targeted for large public venues requiring multi-operator support and provides extensible multi-technology (2G/3G/4G), multi-band operations. As the number of large new venues becomes scarce, the number of DAS node deployments will gradually decline, supplemented by the growth in small cell and booster deployments. Future DAS deployments are expected to come increasingly from system upgrades at large public venues and new constructions.

Small Cells including DRS/RRH systems like Ericsson's Radio Dot and Huawei's LampSite will represent the biggest growth category over the next few years in terms of node shipments, growing at over 20% CAGR from 2017 to 2023. Mobile Experts forecasts that the number of DRS/RRH radio node shipments will double in three years to over 1.5M units in 2020. It should be reminded that this strong growth is largely due to the fact that the operators in China as directly making the investment for enterprise mobile infrastructure deployments. The indoor small cells are expected to grow at a moderate pace, i.e., 7% CAGR from 2017 to 2023. Some of these indoor small cells will be leveraged as a local signal source for boosters and in some instances for "Light" DAS systems.

Signal boosters or repeaters will also see a strong double-digit growth in high teens as low-density enterprise venues, and light industrial complexes will be well-suited for extending

mobile coverage indoors with boosters with "off-air" configuration. By tapping macro towers (base stations) nearby, signal boosters are natural multi-operator solutions with a low initial CAPEX profile (i.e., around $0.15 per sq foot for standalone single BDA, or $0.35 per sq foot for a "smart" booster like Nextivity's QUATRA).

DAS Outlook

With product features to handle multiple frequency bands and the different air interface technologies concurrently, DAS offers the most comprehensive feature sets and flexibility to handle a complex array of multi-operator requirements in large public venues like stadiums where people consume and generate enormous amounts of traffic every year. According to recent mobile traffic statistics from the Super Bowl held in Minneapolis earlier this year, three of the major operators, Verizon, AT&T, and Sprint combined, handled over 50TB of cellular data traffic in and around the US Bank stadium. While DAS remains most capable and flexible product for in-building mobile infrastructure system, the primary target market for DAS -- i.e., large public venues like stadiums and airports – is beginning to tap out. While system upgrades every 5-8 years will continue to fuel DAS investments going forward, Mobile Experts estimates that direct mobile operator investments are expected to decline over time. In fact, this trend is already happening for major DAS vendors who have relied on the operator-funding model to fuel their growth.

Despite the decline in direct operator investment in DAS projects, some large and tech-savvy enterprises are taking direct control of their mobile infrastructure needs. The decision to retrofit an enterprise campus is even more straightforward when it comes to new constructions. Planning ahead of new construction projects to install a DAS system can greatly enhance mobile work environment. As DAS suppliers revamp their product lines to reduce complexity and lower installation costs, we expect these measures to open up so-called "middleprise" market. While we have seen some efforts to open up this price-sensitive enterprise market through combining small cells and DAS systems ("Embedded DAS" as referenced in our DAS reports), this "middleprise" market has been tough to crack as the traditional DAS ecosystem of system integrators have relied on labor installation component to make the money. More importantly, the time delay associated with sourcing signal via operators has been a key obstacle. Enterprises are accustomed to an installation projects taking several weeks, not several months. Despite these challenges, we expect enterprise-driven "Light" DAS deployments targeting one or two major operator support to lower the initial CAPEX cost to target price-sensitive enterprises.

Neutral host providers will continue to play a critical role in providing shared infrastructure economics for smaller enterprises who lack the will to make relatively large up-front investments and more importantly, the skillset to coordinate with mobile operators and manage the complex RF systems like DAS. Mobile Experts believes that the neutral host providers and some large enterprises will continue to drive the DAS radio node shipments at from less than 500K indoor DAS nodes in 2017 to over 800K DAS nodes in 2023.

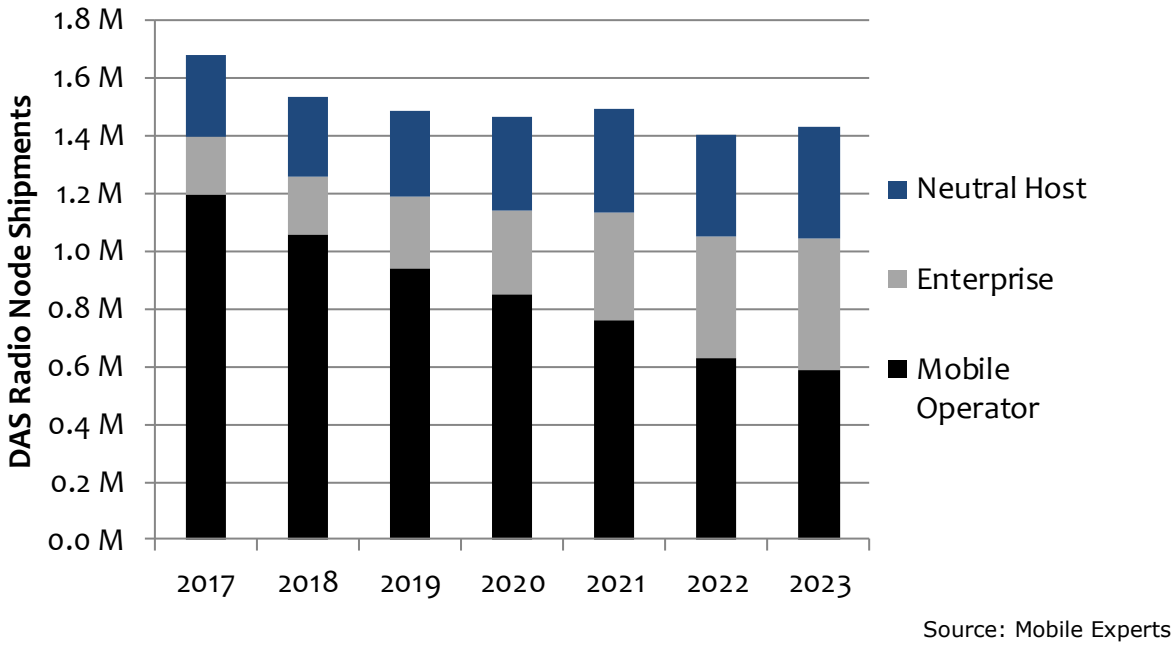
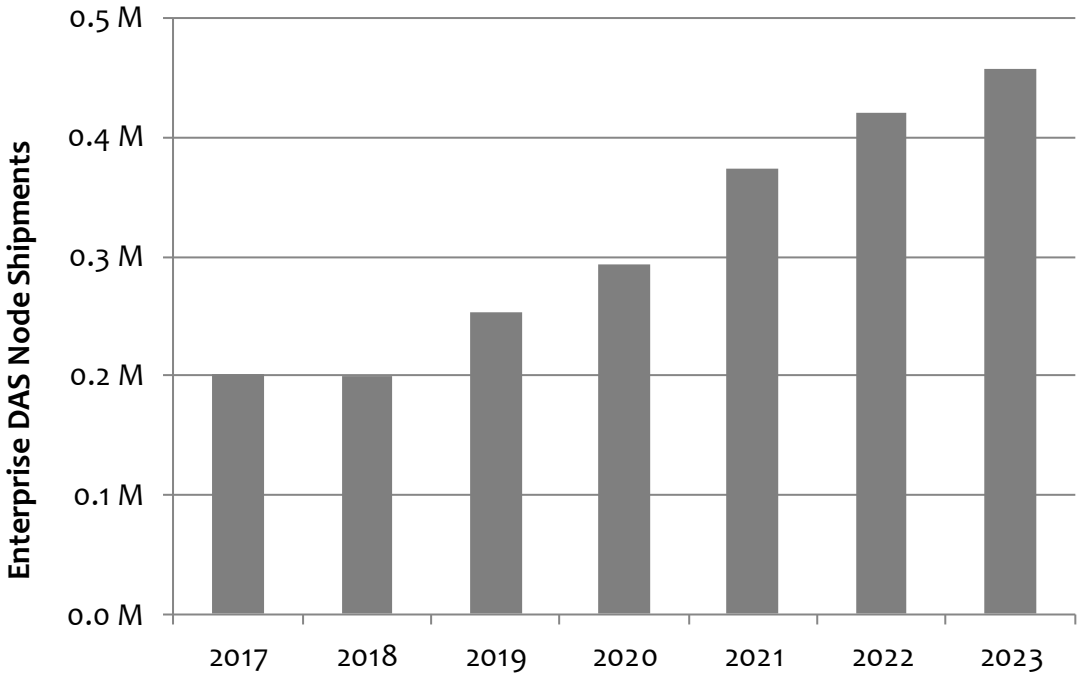


Chart 4: Indoor DAS Radio Node Shipment by Ownership, 2017-2023

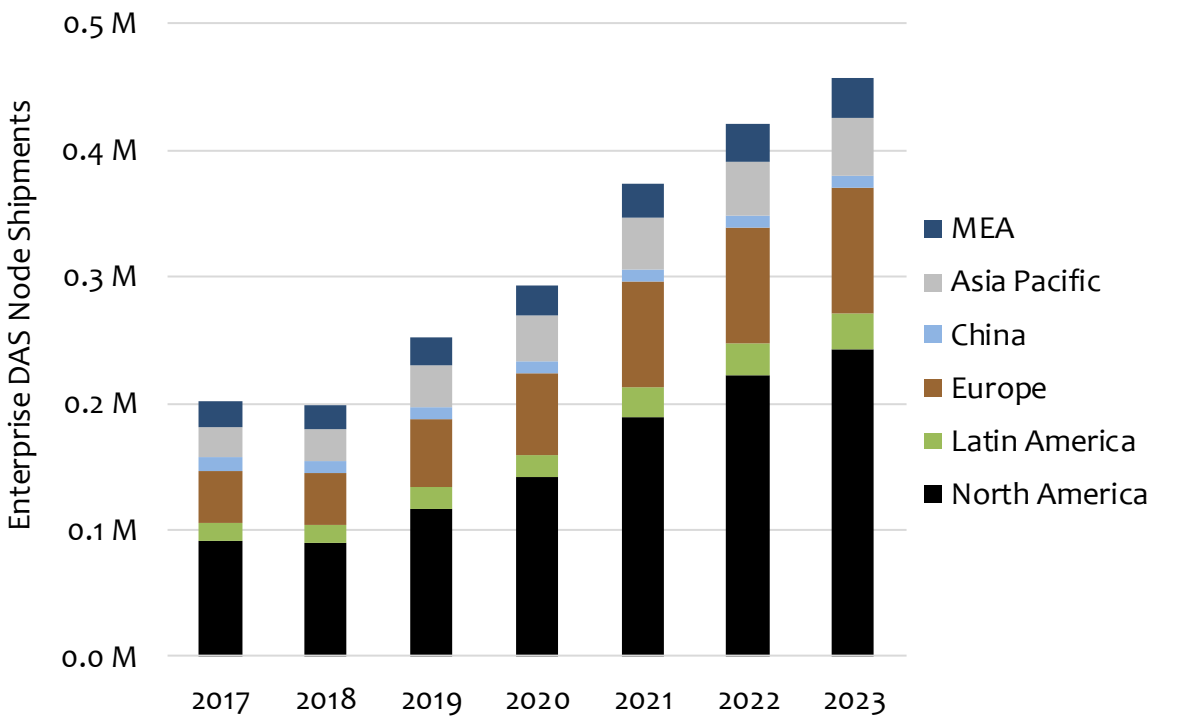
As DAS systems targeted for the enterprise market continue to get optimized to lower the overall cost, including cabling, installation, and on-going management, Mobile Experts believes that an increasing number of enterprises may be open to deploying DAS systems that provide multi-operator support. Assuming that DAS suppliers are able to introduce cost-effective DAS systems that provide multi-operator support capability, even if initial deployments may only support one or two operators to start, Mobile Experts estimates that the Enterprise DAS market alone can grow at 15% CAGR from about 200K DAS nodes in 2017 to over 450K DAS nodes in 2023.



Source: Mobile Experts

Chart 5: Enterprise DAS Radio Node Shipments, 2017-2023

A bulk of the DAS market resides in the United States, primarily due to a strong ecosystem of system integrators and value-added resellers that can assist with the complex process of regulatory permitting, mobile operator coordination of securing signal source, and a sundry list of design, installation, and RF tuning processes that often complicate and perplex many enterprise IT/telecom departments. The UK and a few Asian and European countries will follow with enterprise DAS deployments of their own. With the popularity of DRS and RRH deployments by mobile operators in China and Southeast Asia, the DAS market has not really developed in those regions. Mobile Experts foresees a limited uptake of traditional DAS solutions in the foreseeable future there.



Source: Mobile Experts

Chart 6: Enterprise DAS Radio Node Shipments, by Region, 2017-2023

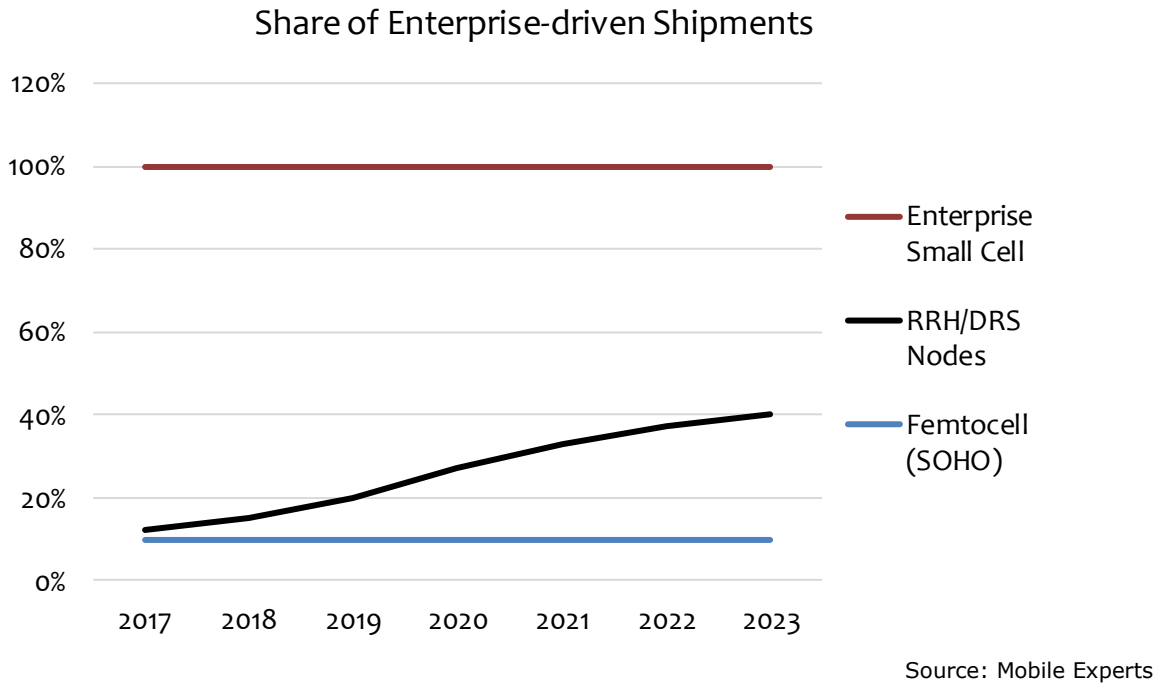
Small Cell (DRS/RRH) Outlook

Small Cell shipments are growing quickly as detailed in our Small Cells report published earlier this year. Driven by direct operator investments of indoor systems, particularly in China and APAC, the shipment of carrier indoor small cells including Distributed Radio Systems (DRS) such as Ericsson's Radio Dot and Huawei's LampSite has grown rapidly to address coverage and capacity demands indoors. For the enterprise mobile infrastructure market, we specifically highlight the following small cell types:

- *RRH/DRS* radio nodes often deployed by a mobile operator to address indoor coverage and capacity issues;
- *Enterprise Small Cells* targeting large enterprise (IT) customers; and,
- *SOHO Femtocells* that small home office customers can purchase directly from mobile operators to address indoor coverage issues at home or small office environments.

Mobile Experts estimates that about 10% of Femtocells are deployed for 'enterprise-driven' needs every year and that Enterprise Small Cells are, by definition, 100% targeted for the enterprise market. While the bulk of DRS/RRH radio nodes are deployed by mobile operators today, we estimate that more and more of these units will be 'enterprise-driven' over time as DRS/RRH vendors position these units as a 'platform' for value-added services

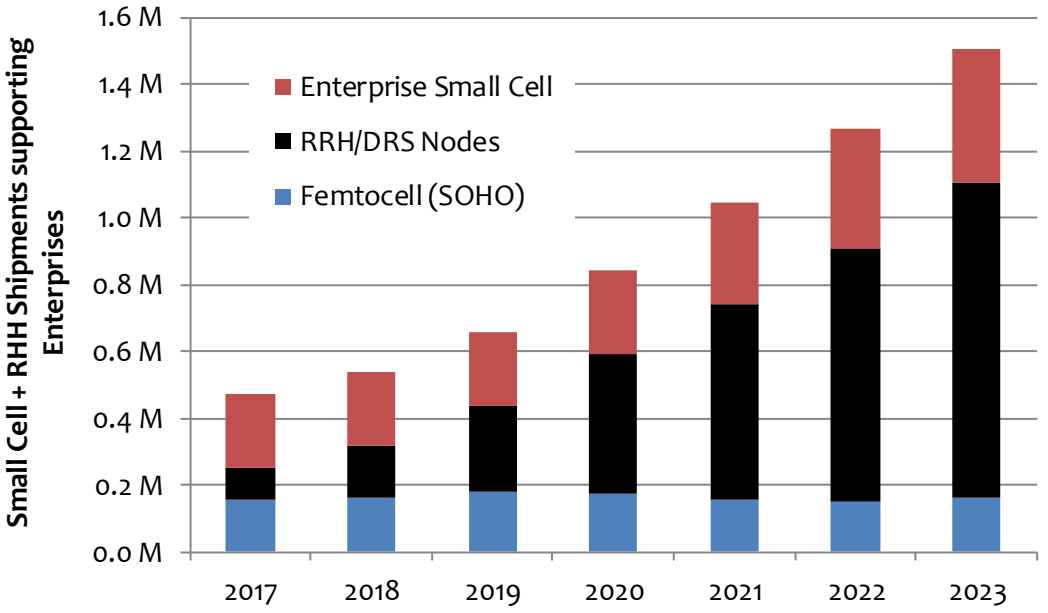
such as location and advertising services. With the rapid uptake of DRS/RRH units like Ericsson's Radio Dot and Huawei's LampSite in the past couple of years, we expect the vendors to position the DRS/RRH units as enterprise products. A key challenge for DRS vendor solutions is to overcome its perceived positioning as a single-operator solution. With no meaningful footprint for the Chinese vendors, Huawei and ZTE, Ericsson remains a sole DRS vendor in the largest and most competitive North American market.



Source: Mobile Experts

Chart 7: Enterprise-Driven Share of In-Building Small Cell (RRH+DRS) Shipments, 2017-2023

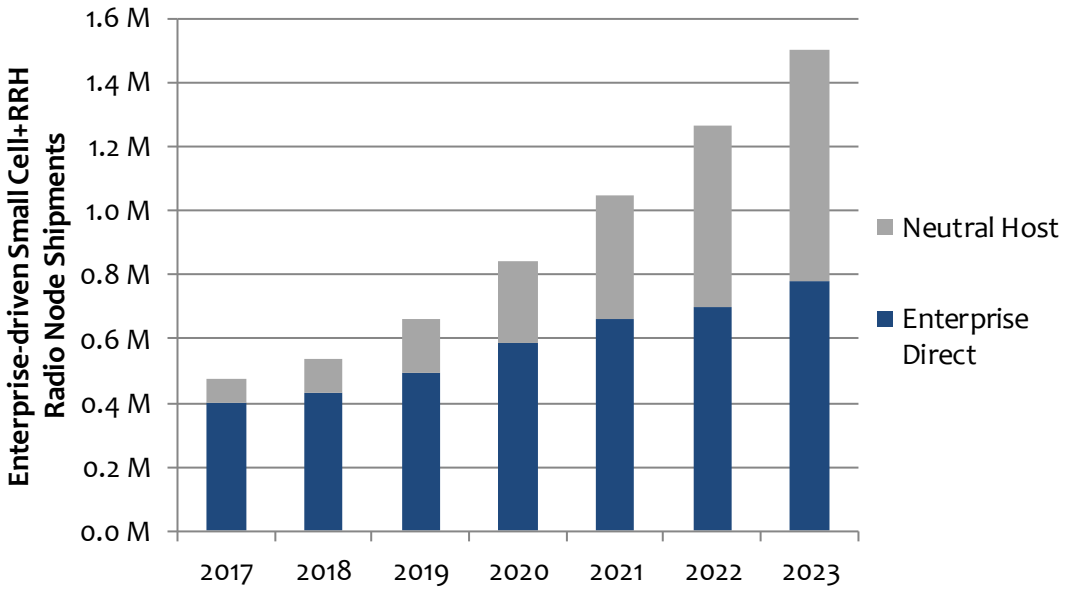
With the scalability of deploying small cells where needed and operator preference for C-RAN architecture, Mobile Experts believes that RRH-based DRS has a good chance to grow share among the different small cell types including standalone integrated Enterprise Small Cells and SOHO Femtocells. A key challenge is to convince the traditional cellular system integrators to adopt DRS vs. traditional DAS, and/or establishing a new ecosystem of DRS system integrators, perhaps tapping into the broad ecosystem of Wi-Fi centric IT integrators.



Source: Mobile Experts

Chart 8: Enterprise-Driven Small Cell (RRH/DRS/Integrated) Shipments, 2017-2023

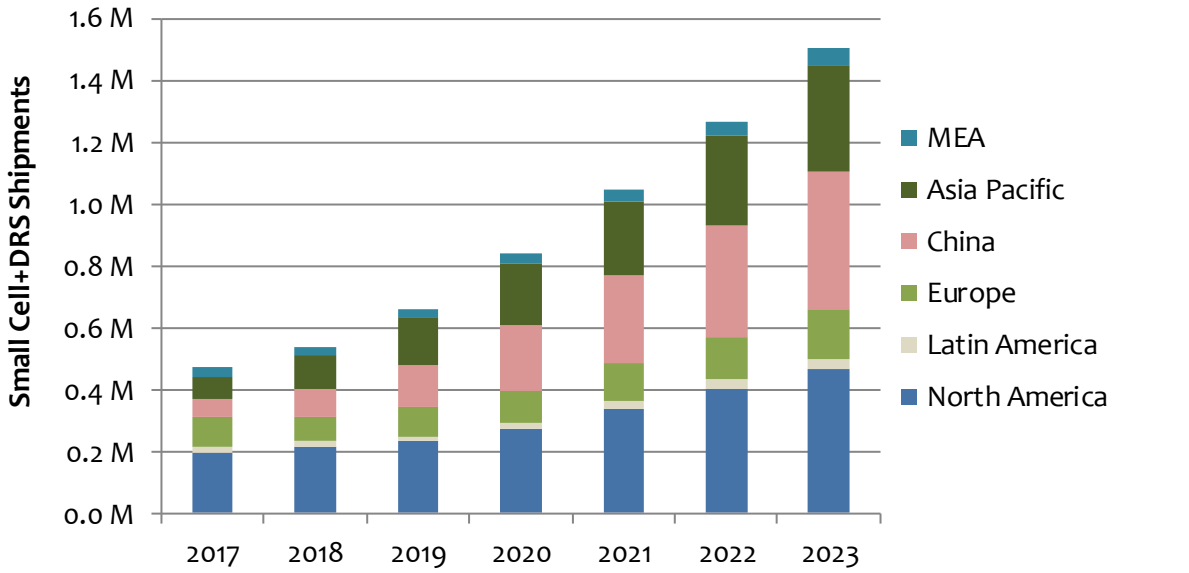
As the market moves down market to smaller venues and enterprises, neutral host providers will play a bigger role in deployment of Small Cell radio units. Smaller enterprises will look to telecom-savvy neutral host providers to act on their behalf to design, install and manage Small Cell infrastructure and help coordinate network integration and connectivity with mobile operator core networks for seamless mobile connectivity in and out of buildings.



Source: Mobile Experts

Chart 9: Enterprise-Driven Small Cell/DRS Shipments, by Channel, 2017-2023

Small cells have a strong operator support in Europe, China, Korea, Japan, and the USA. We expect balanced growth in multiple countries. We expect DRS systems will find enterprise-related success in China, Asia Pacific, and Middle Eastern markets where Huawei has an installed base of customers and operators seem more likely to make direct investment. In many of these countries, local technicians do not have the skill level to integrate a small cell solution, so the Tier 1 vendor, Huawei or Ericsson, will be called in to handle the enterprise in-building solution. In North America, Ericsson may face more competition from traditional DAS vendors who have established relationships with important system integrators who sometimes call into enterprises for in-building wireless contracts.



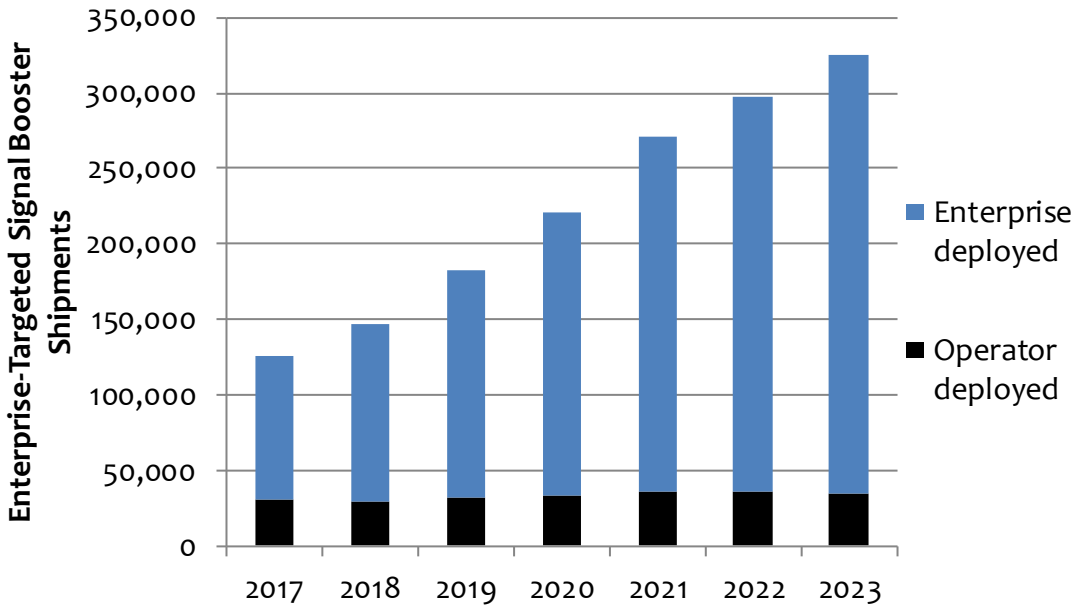
Source: Mobile Experts

Chart 10: Enterprise-Driven Small Cell/DRS Shipments, by Region, 2017-2023

Signal Booster Outlook

In last year's report, Mobile Experts focused on the operator-sanctioned "carrier repeaters" which have been approved by the FCC in the USA and being adopted in a few countries in other regions. In this year's report, we further segment the "carrier repeaters" based on who deploys the units. Mobile Experts estimates that a small portion of the "carrier repeaters" to be deployed by operators to satisfy indoor needs in rural and less-dense environments where macro base stations are lightly loaded – thus extending mobile coverage to handle indoor traffic via macro base station nearby won't negatively impact the macro network performance very much. In fact, it may perhaps be viewed as better utilization of macro network resources more effectively while providing good user experience indoors.

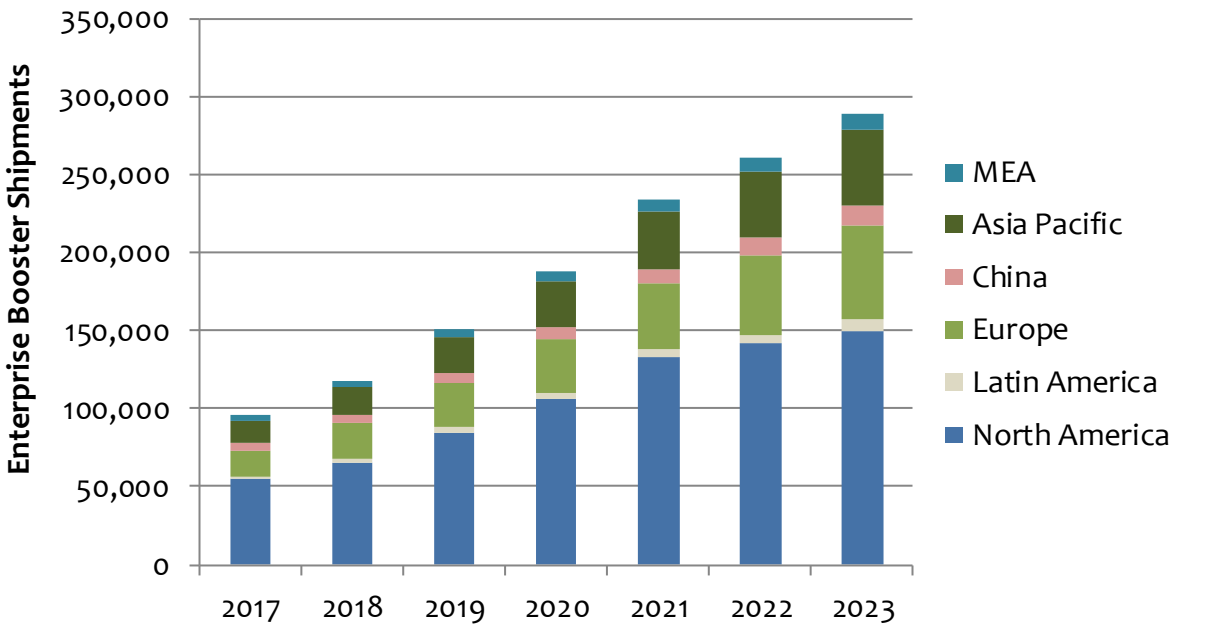
With ease of use and low cost, boosters are viewed as ideal multi-operator solution for many enterprises. However, its use will be limited by the operators who will likely forbid its use in urban areas where traffic density is already very high and put strain on macro network performance. Where permitted, boosters will find home for many enterprises looking to cover low-density venues like warehouses, especially those in rural areas with plenty of macro base station capacity nearby. Mobile Experts estimates that between 60-70% of booster units will be deployed by enterprises and about 10-20% by operators in developing regions.



Source: Mobile Experts

Chart 11: Enterprise Signal Booster Shipments, 2017-2023

Boosters or repeaters are used all over the world. With the FCC ruling to allow operator-sanctioned devices to be sold legally, the repeater market has experienced strong growth in recent years. As the USA takes advantage of these "carrier repeaters," other countries are beginning to adopt their use as well. "Smart" boosters that provide broader and scalable coverage through "stacking of multiple systems" are seen by some operators as "lighter," and presumably cheaper, version of active DAS system, to supplement their mobile coverage indoors especially those operators seeking targeted approach of enhance mobile coverage.

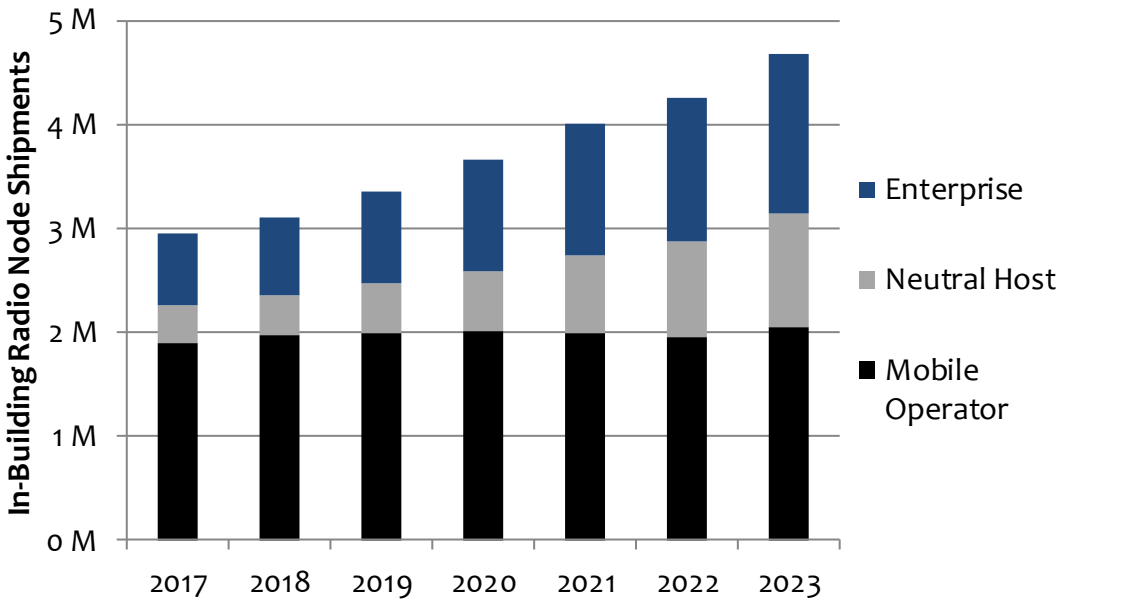


Source: Mobile Experts

Chart 12: Enterprise Repeater Shipments, by Region, 2017-2023

Operator vs. Neutral Host vs. Enterprise-Direct Deployments

Today, over 70% of all in-building radio nodes are deployed by mobile operators either directly or indirectly through neutral host providers, primarily through DAS infrastructure to extend mobile coverage and capacity indoors at marquee venues such as sports stadiums and major airports. With the mobile operators in developed markets focusing their attention towards 5G over the next several years, their capital allocation for in-building wireless projects is increasingly becoming scarce. With a growing opportunity to address pent-up demand for mobile infrastructure, we are seeing neutral host providers and large enterprises to more directly fund and deploy in-building systems. For example, some large stadium owners are taking the lead in funding neutral-host indoor systems. With the complexity of deploying and maintaining mobile infrastructure systems that require coordination with multiple operators, the neutral host providers will play a key intermediary role in design, deployment and on-going maintenance of mobile infrastructure systems, on behalf of enterprises, going forward.



Source: Mobile Experts

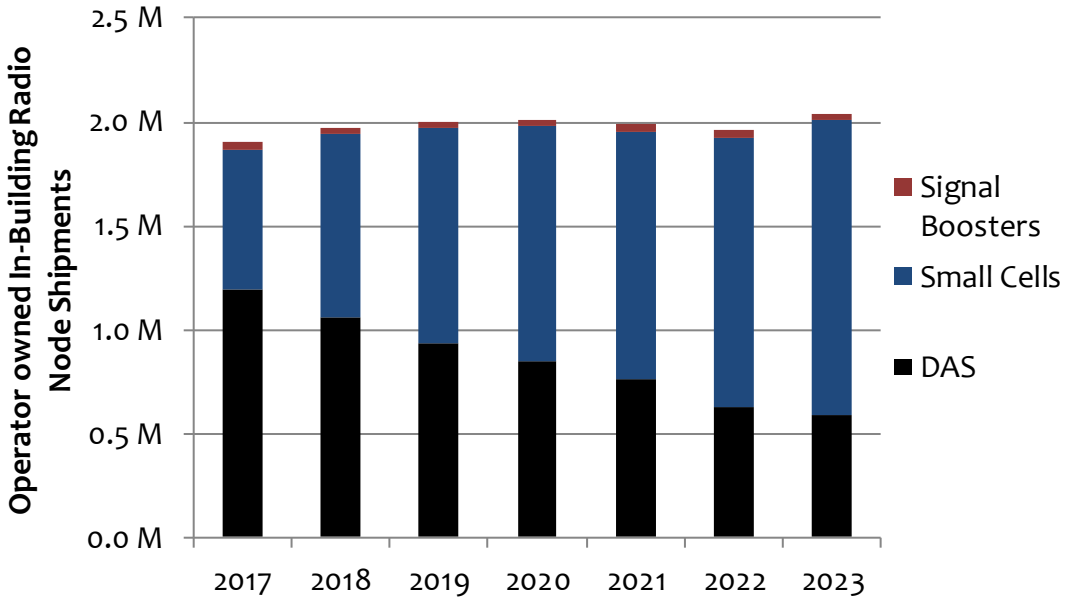
Chart 13: In-Building Radio Node Shipment by Ownership, 2017-2023

In-building wireless technology and product deployment differs by business stakeholders. Mobile operator requirement for in-building wireless system differs from small enterprises. Mobile operators require advanced systems that can support multiple air interface technologies and frequency bands, and demand control and management capabilities that are on par with very large macro RF network systems. Meanwhile, small enterprises will demand low-cost systems that are easy to deploy and manage and provide seamless mobile voice and data services. These diverse requirements drive different preferences and choices for cellular in-building wireless systems for operators, neutral host providers, and enterprises.

Mobile operators are telecom-savvy experts and have relied on "shared" infrastructure like DAS for high-density, public venues like sporting stadiums and airports for years. As the small cells technology matures and provides control and management capability close on-par with their macro infrastructure, they are likely to prefer small cells for smaller (but still large) enterprise venues like corporate campuses, high-rise buildings, etc., where a business case dictates direct investment. With increasing availability of operator-approved enterprise small cells, Mobile Experts expects small cells, including DRS systems from Ericsson and Huawei, to be deployed by the mobile operators in increasing numbers, raising its share of radio node shipment from over 35% of total mobile operator in-building radio node deployments in 2017 to 70% in 2023.

The direct mobile operator deployment of in-building radio nodes will remain relatively flat over the forecast period from 2017 to 2023 as the operators in the USA generally pull back from in-building projects. The number of mobile operator owned DAS nodes is forecasted to

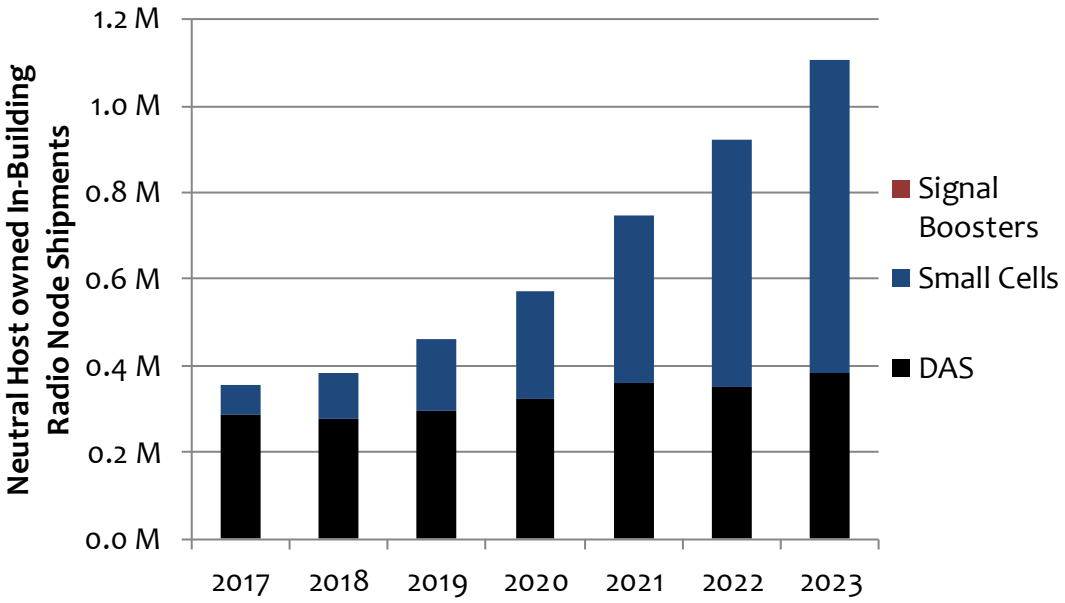
decline over 10% CAGR during our forecast period (2017-2023) while the Small Cell radio nodes to grow at about 13%. Operators will selectively deploy boosters to extend mobile coverage in key enterprises in places where nearby macro base stations are not heavily loaded. The absolute number of operator-deployed boosters will remain small.



Source: Mobile Experts

Chart 14: Mobile Operator-owned In-Building Radio Node Shipment by Product, 2017-2023

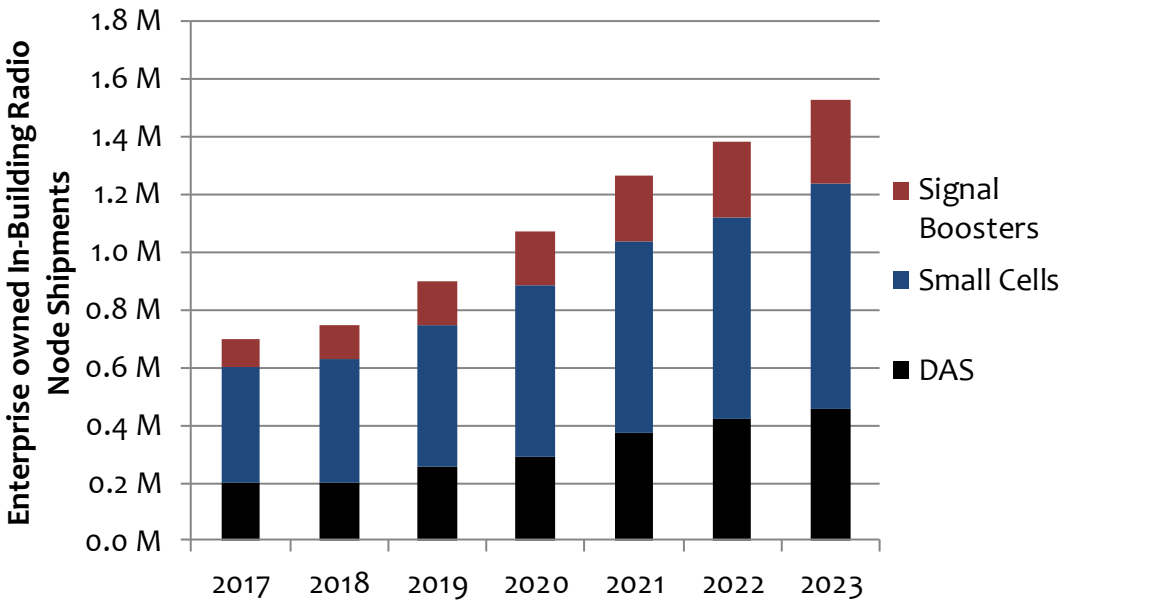
Neutral-host providers play an important role in the telecommunication infrastructure market. Players like American Tower, Crown Castle, Extenet, and others enable a shared infrastructure business model that lowers a burden for the high fixed-cost industry at large. Today, a majority of neutral host providers focus on very large public venues like stadiums, airports, and hi-rise commercial buildings that are of interest to mobile operators and large enterprises alike. As the players begin to address large numbers of smaller venues across other vertical industries such as hospitality, healthcare, commercial real estate, etc., we expect the neutral host providers to address some of the smaller venue opportunities with a portfolio of cost-effective in-building cellular systems like boosters, small cells, and "Light" DAS systems. Mobile Experts expects the neutral host providers to continue to deploy increasing number of DAS nodes at over 5% CAGR while significantly expanding the Small Cells deployment at over 45% CAGR during the forecast period. The in-building radio node deployment by neutral host providers is expected to see the greatest increase in comparison to the mobile operator or direct enterprise deployments.



Source: Mobile Experts

Chart 15: Neutral Host-owned In-Building Radio Node Shipment by Product, 2017-2023

Enterprises can range from a very small "small office home office" (SOHO) type with one or two workers working out of home or small commercial space to an international conglomerate with tens of thousands of workers in a corporate headquarter campus environment. This wide range of enterprises naturally results in a variety of in-building mobile infrastructure solutions. While very small enterprises may be fine with SOHO-targeted Femtocells connected to high-speed Internet for backhaul, very large enterprises with hi-rise buildings or large campus environment will likely require a large DAS, or perhaps a network of Enterprise Small Cells, that enable seamless mobile services in and out of campus environments. Mobile Experts estimates about 150K SOHO Femtocells will be deployed by very small enterprises annually. Also, we estimate that some small enterprises and light industrial enterprises with large warehouse-like venues with limited mobile usage will deploy signal boosters or repeaters to extend macro coverage indoors. Large enterprises with very high mobile capacity requirements will continue to rely on DAS systems that can provide a multi-operator, mobile coverage/capacity solution. With growing demand across various vertical segments, both large and small, Mobile Experts expects about 8% CAGR growth across the DAS, Small Cell, and Repeater product segments.

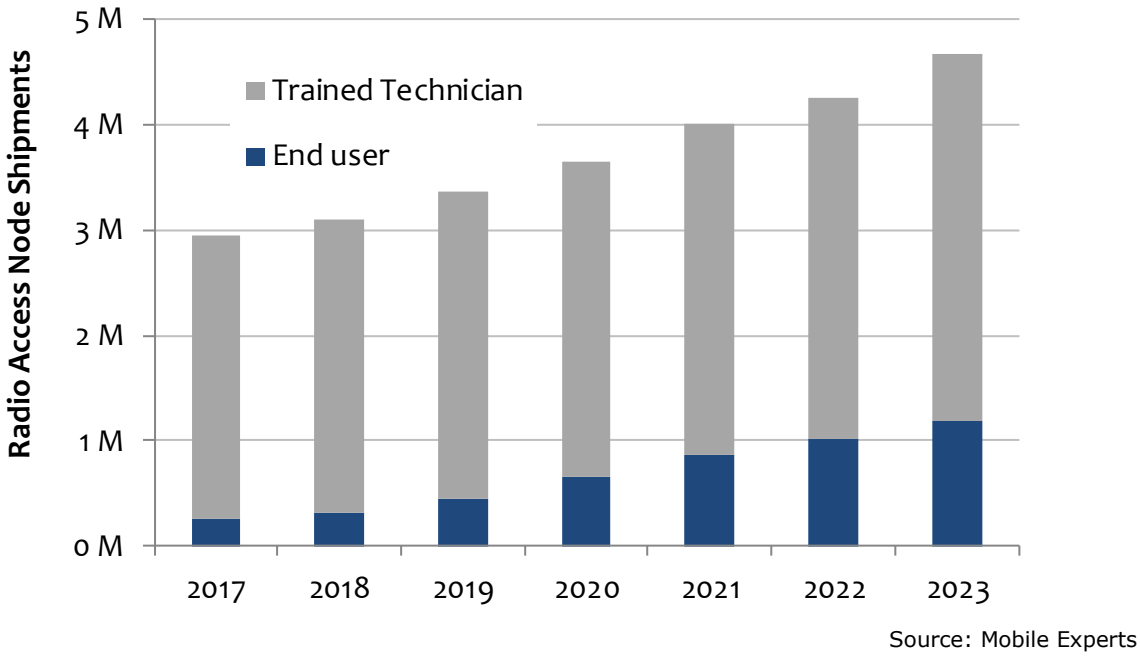


Source: Mobile Experts

Chart 16: Enterprise-owned In-Building Radio Node Shipment by Product, 2017-2023

Outlook for Self-Installation

DAS and non-residential Enterprise Small Cells have always been installed by highly trained technicians. These complex systems require careful RF planning and design, careful measurements, walk-through testing, and configuration management, that is tough to master for traditional IT staff. Today, the bulk of "self-installable" enterprise mobile infrastructure product is made up of small office/home office (SOHO) targeted Femtocells that home office enterprise customers can purchase directly from mobile operators to enhance mobile coverage in home and small enterprise environments where macro base station coverage is weak. For larger enterprise venues, Mobile Experts expects skilled technicians from system integrator community will be required to handle the initial RF planning and system optimization. Enterprise small cells and "smart" booster products will ease some aspects of RF optimization, but the initial system design and RF planning will continue to be handled by skilled technicians. While we still believe that CBRS neutral host small cells will be self-installable, similar to Wi-Fi, but operator approval and core network integration will be crucial to enable this feature.



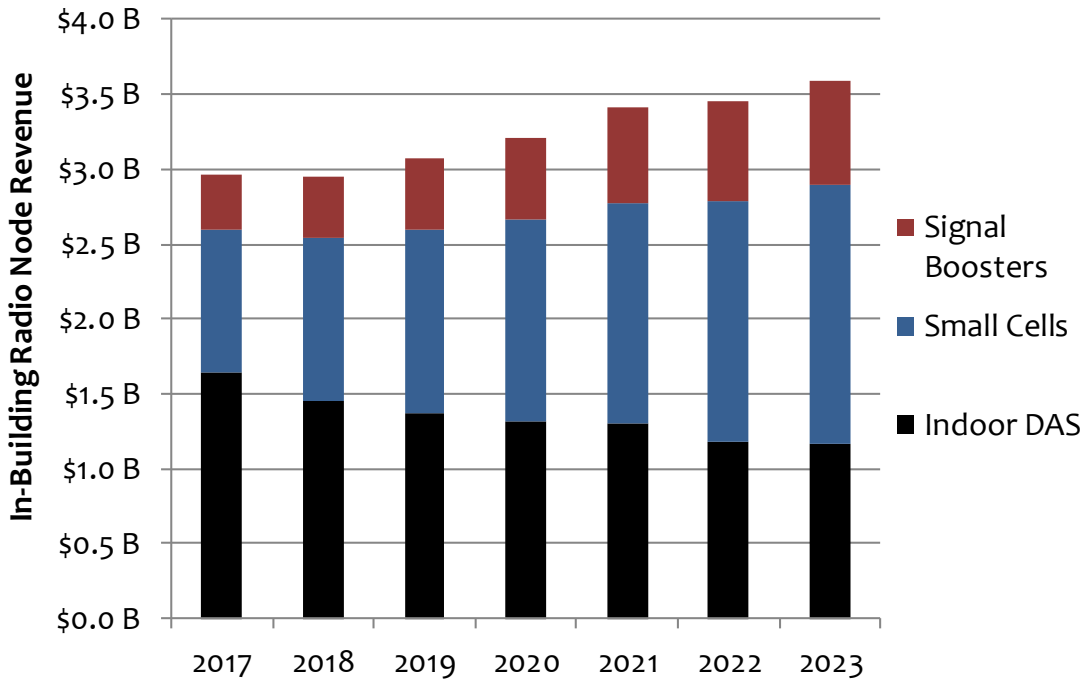
Source: Mobile Experts

Chart 17: Enterprise Mobile Infrastructure Revenue Outlook, 2017-2023

At the end of our forecast period, Mobile Experts expects over 75% of mobile infrastructure radio nodes will still be deployed by trained technicians and that neutral host providers, and telecom-focused system integrators will continue to play an important role in addressing the needs of enterprises seeking cellular in-building wireless infrastructure.

8 REVENUE FORECAST

The *Enterprise Mobile Infrastructure* market is dominated by DAS today as they hold the premium tier of the market such as stadiums which demand maximum flexibility to support many operators and multiple bands. While DAS will remain a sizable portion of the overall enterprise mobile infrastructure market, small cells and boosters will become increasing role as the market expands "down market" to address smaller venues. Mobile Experts expects small cell products, including DRS systems (e.g., Huawei's LampSite and Ericsson's Radio Dot), to drive the overall market outlook in terms of revenue as primarily operators look to these "digitized" remote radio nodes to expand RF distribution leveraging structured IT cabling (Cat 5/6) to lower the initial CAPEX cost. In a similar fashion, boosters especially "smart" boosters that network multiple remote radio units to a centralized network unit to actively manage RF signal distribution are expected to become more popular as they provide relatively low installed cost.



Source: Mobile Experts

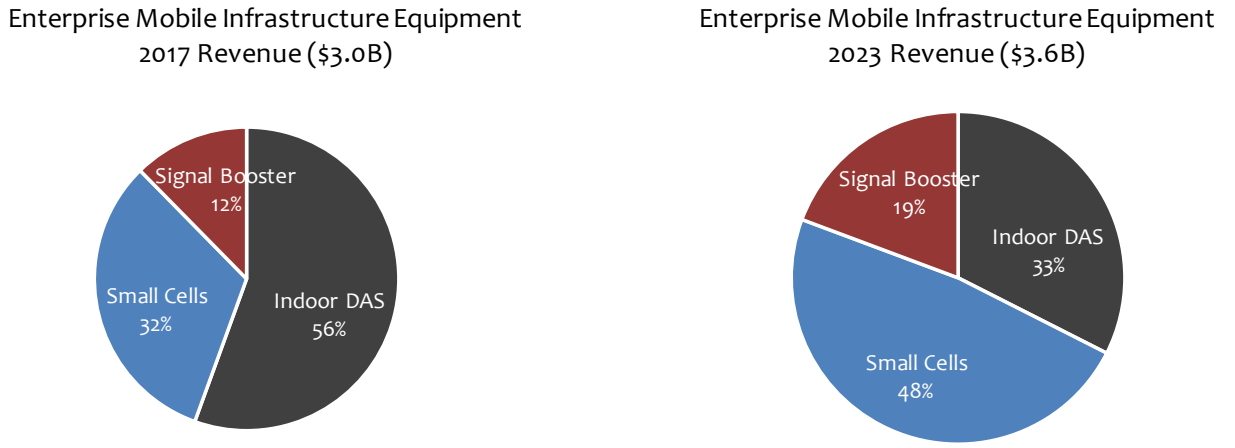
Chart 18: Enterprise Mobile Infrastructure Revenue Outlook, 2017-2023

Mobile Experts forecasts the overall Enterprise Mobile Infrastructure market to grow from just under $3.0B in 2017 to $3.6B in 2023.

- The DAS market segment is expected to grow in low single digits to constitute about $1.84B in 2022.

- The Small Cells market segment including DRS and RRH radio units to grow at 10% annually from around $950M in 2017 to $1.7B in 2023. The DRS/RRH small cell segment is expected to grow faster than standalone integrated small cells.
- Lastly, the Signal Booster market segment is expected to grow from about $360M in 2017 to about $690M in 2023.

As the enterprise mobile infrastructure market expands beyond large marquee venues to smaller enterprises, Small Cells and Repeaters will make up increasing share of the market, growing from a combined 44% of the total enterprise mobile infrastructure equipment revenue in 2017 to almost 70% in 2023.



Source: Mobile Experts

Chart 19: Enterprise Mobile Infrastructure Revenue Share by Product, 2017 to 2023

9 COMPANY PROFILES

Accelleran

Accelleran is a small cell OEM startup based out of Belgium focusing efforts to produce LTE TDD small cells, targeting both licensed bands and shared 3.5GHz CBRS band for the US. At MWC 2017, the company released its CBRS small cell based on Cavium SoC. The company has a few trials ongoing with cable and OTT operators in the US to pursue the CBRS market opportunities.

Advanced RF Technologies (ADRF)

ADRF has expanded as a supplier. In addition to their previous repeater/booster products, it has a couple of generations of active DAS products. The company has strong direct relationships with Verizon and Sprint and has expanded its product portfolio with modular and compact ADXV product line. The company also has a broad product portfolio of public safety systems including digital repeaters and DAS covering the full breadth of public safety frequency bands across UHF, VHF, 700, and 800MHz.

Airspan

Airspan Networks has developed a line of LTE small cells, including indoor enterprise units and outdoor units with integrated wireless backhaul. The company introduced LTE Relay system to boost network efficiency at cell edge. The company has deployed tens of thousands of small cells in India, as well as successful relationships with Softbank in Japan and with Sprint in the US. With successful small cell deployments, the company has tripled its employee base to pursue growing opportunities in North America, APAC, and MEA.

American Tower Corp

American Tower is a major wireless infrastructure provider with a global presence in North America, Europe, South America, India, and Africa. The company operates about 150,000 wireless communication sites globally. In addition to its primary business of operating over 40,000 cell towers in the United States, the company has more than 1300 buildings under management and provides in-building DAS services mainly at large venues such as airports, malls, campuses, hospitals, casino resorts, etc. Moreover, the company manages hundreds of outdoor DAS nodes. With its core business of providing shared wireless infrastructure services, the company has strong relationships with all major operators and has a good growth prospect as a neutral host provider in the in-building space.

Argela

Argela has close connections with Turkish mobile operators. As a part of Turk Telekom Group, Argela has a more direct route to market than other femtocell suppliers. The

company has developed a line of 3G and LTE small cells, which has had only limited success on the wider market. The company works with Altobridge for small cells for 3G in rural deployment, and they have partnerships with Cisco and NEC for gateways. Recently, the company demonstrated its ProgRAN solution that encompasses the programmable RAN solution based on the NFV/SDN principles based on Cavium's baseband processor platform.

Baicells

Founded in 2014, Baicells is a privately-held company based in Beijing, China. The company's product solutions range from indoor and outdoor small cells, CPEs, and antennas. With a new sales office in the US, the company is expanding into unlicensed and shared spectrum opportunities with cable operators and neutral host providers. The company announced its 'NeutralCell' small cell product at MWC 2017 leveraging 3.5 GHz CBRS.

Bird Technologies (DeltaNode)

Bird Technologies, based in Ohio, acquired DeltaNode in 2013 to add to its repeater portfolio from TX RX Systems. Deltanode is a Swedish company that was spun out of SHL Group with extensive RF talent from Ericsson and Allgon. The company provides indoor and outdoor DAS equipment. While the company's primary business is in test and measurement, the Deltanode DAS products have resonated with customers in Canada, Europe, and Latin America, looking for custom designs.

Black Box Network Services

Black Box acquired Inner Wireless in late 2012 and together they have focused intently on support of multimode DAS systems for enterprise applications. Healthcare is a focus for the company, with large buildings and complex Wi-Fi installation scenarios. The combination of Wi-Fi and mobile system integration is a differentiator for Black Box.

Boingo

Boingo has transitioned from a Wi-Fi centric business model to a growing neutral-host service provider with over 20,000 DAS nodes in service. In addition, the company runs DAS and Wi-Fi networks at airports, military bases and other public venues. The company has expanded beyond core airport venues to malls, hotels and a few military bases.

BTI Wireless

Founded in 1999, BTI has grown from a power amplifier supplier to a supplier of in-building repeater systems, outdoor DAS systems, remote radio heads, and other products. BTI has major facilities in Southern California and Shenzen, China. The company has a sizable base of DAS deployments in Canada, Australia, and southeast Asia.

Cisco

Cisco's global footprint and channel sale partnerships especially in enterprise IT segment bolds well for its small cell solutions. Cisco has been working to arrange the business conditions for mobile operators and enterprises to support the upgrade from Wi-Fi to licensed/unlicensed operation. Endorsements from several tier-one mobile operators including Vodafone and EE have validated the Cisco enterprise approach. Cisco's strategic partnerships with SpiderCloud for enterprise small cell segment and also with the larger Ericsson partnership bolds well for its wider aspiration to increase share in the service provider segment, and small cell is expected to be a meaningful part of its offering to service providers. Cisco's "direct-to-enterprise" small cell strategy appears to have changed recently, as it plans to open its clip-on interface to small cell partners instead. Cisco's wireless strategy is still largely planted in Wi-Fi and IEEE 802.11 roadmap.

Cobham Wireless

Cobham Wireless was formed in early 2015 by combining Axell Wireless acquired in 2013, with Aeroflex, which Cobham acquired in 2014. The rationale is that the test and measurement assets and expertise of Aeroflex would provide synergies to the combined company. Axell holds a strong market share in the European DAS market, with unique products that are tailored for high mobility coverage in tunnels and remote areas. Axell routinely integrates public safety radio with digital repeaters and has shifted from passive to active DAS in deployments. Axell also provides DAS for some high-density applications such as stadiums in Europe. The company has introduced a product called "Intelligent digital DAS" (idDAS) which allows for dynamic capacity allocation similar to other active DAS systems. The company has recently refocused its wireless business mainly on the traditional DAS business.

Comba Telecom

Comba is the main DAS supplier in China and other cost-sensitive markets. The company has recently focused on Latin America with several stadium deployments. The company has also worked together with top-tier OEMs in deployment of radio heads for high-density indoor/outdoor applications. The company supplies a wide range of repeaters, DAS radio heads, TMAs, residential and indoor small cells, and other coverage related products. Their use of repeaters together with DAS has resulted in some low-cost projects.

Commscope

Commscope is a leader in both indoor and outdoor DAS markets, with multi-operator products tailored for both market segments. Commscope's acquisitions of TE Connectivity for DAS and Airvana for small cell (in 2015) have been foundational for its in-building wireless business. With TE, Commscope gains digital DAS IP. With Airvana, they gain small cell IP

portfolio. Commscope is working with several major operators in Europe and North America to get its OneCell product approved. While its leading position in DAS provides good customer and partner relationships in the in-building wireless market, it is being challenged with competition and cost pressures.

Communications Components Inc.

CCI, based in New Jersey, USA, directly supports mobile operators for unique coverage challenges. CCI's primary business was built on co-siting and combining products for 2G/3G networks. CCI also offers a line of bi-directional amplifiers and DAS interface units for in-building applications and has been very successful with major carriers such as Verizon and AT&T, working as a system integrator to pull together DAS and RF solutions.

Connectivity Wireless

Connectivity Wireless is a prototypical system integrator/solution services company that specializes in full DAS design, deployment services to multiple vertical sectors, including hospitality, hospitals, stadium and commercial buildings. With over 2000 DAS deployment projects under its "belt," the company has seen a rapid growth.

Contela

Contela had provided femtocells and related gateways for the Japanese and Korean markets and has ramped to significant volume of LTE small cells to SK Telecom. The company has been able to successfully penetrate at least two major customers outside of the Korean market, with significant shipments during 2015. Most recently, the company has joined the CBRS Alliance.

Corning

Corning acquired fast-growing MobileAccess in 2011 and has continued the company's strong push into in-building DAS systems. Mobile Access serves enterprise customers, neutral hosts, and a few operators with in-building distribution systems. The company offers multiple product lines, targeted at 2G, 3G, and now 4G systems with MIMO support for either WiMAX or LTE. The Corning ONE product offers dynamic capacity allocation with an all-fiber DAS network. More recently, in 2017, the company acquired Spidercloud to augment its in-building wireless portfolio to address enterprise mobile infrastructure opportunities. Corning has a variety of products in in-building wireless space, including DAS, Small Cells (from Spidercloud), and RF planning tool business of iBwave.

Crown Castle International

A traditional wireless tower company that is taking a more active role in the small cell infrastructure business. The company has made several fiber acquisitions in the US to

bolster its small cells business by offering both backhaul transport (primarily dark fiber) and site leases for mobile operator customers to deploy small cells or outdoor DAS remote radio heads in key markets. The company's wireless infrastructure consists of 40,000 towers and 60,000 route miles of fiber.

Dali Wireless

Dali offers a distributed radio system with dynamic capacity allocation, essentially making RF "routable" like an IP router. The company has focused on patents, with more than 300 patents, many of which relate to the use of CPRI and other IP formats to implement adaptive traffic capacity in DAS. The company has some interesting enterprise installations such as the Hilton in Los Angeles and the Dallas/Fort Worth Airport. The company headquartered in Silicon Valley with research and development office in Vancouver, Canada.

Ericsson AB

Ericsson is a tier 1 mobile infrastructure vendor whose Radio Dot product is similar to other DRS architecture solutions like Huawei's LampSite and ZTE's QCell. During 2017, Ericsson introduced 'multi-operator' versions of Radio Dot, which can effectively serve multiple operators through multiple remote units in a common enclosure, with electrically separated Cat 6 cables, or sharing a common Radio Dot system among multiple operators with one lead operator managing the system.

Extenet Systems

Extenet Systems is a privately-held wireless infrastructure provider of distributed networks. As a part of broader Digital Bridge holdings, the company designs, owns, and operates neutral-host networks leveraging multiple technologies including small cells, Wi-Fi, RRH, DAS, and other technologies on behalf of mobile operators and enterprise customers. The company recently partnered with Verizon to build out some of Verizon's small cell deployments in the San Francisco Bay area. The company has ongoing projects with many of tier 1 operators in the United States.

Extreme Networks

With a heritage in Ethernet switching and routing, Extreme networks has had some success deploying its networking gear along with Motorola Enterprise Wi-Fi access points into several NFL stadiums, including Gilette in MA, Philadelphia Eagles stadium, and others. Also leveraging the moniker as an official Wi-Fi analytics provider of NFL, it has received several bid wins in other verticals. The company continues to bolster its product portfolio with a planned acquisition of Brocade's data center product/business from Broadcom.

GrenTech

Founded in 1999, GrenTech is headquartered in Shenzen, China. With reported 3000 employees spread across multiple offices in various provinces in China and branch offices overseas, the company's main sales are derived from domestic China market with various RF products, including "multistandard" fiber-based DAS products and repeater solutions.

HPE (Aruba)

Aruba was acquired by HP in May 2015 to provide technology for converged campus solutions. Aruba provides Enterprise Wi-Fi network equipment and related software solutions, including indoor and outdoor campus solutions. Aruba has put more focus into service provider support during the past year and engages in stadiums and other large venues with various operators. Aruba has been gaining share in the Carrier Wi-Fi space with touted differentiation around security backend.

Huaptec

China-based Huaptec has entered the USA market with booster products under the "HiBoost" brand, offering a suite of commercial repeater products that can cover anywhere from 20K to 100K square foot of space. The company also sells residential and vehicle signal repeater products through multiple distribution channels.

Huawei Technologies

Huawei is a shipment leader in non-residential small cells with success of its LampSite product line. The first two generations of LampSite, which can best be described as a low power RRH product with distributed RF, has been hugely popular in China and Southeast Asia. The product provides flexible indoor coverage/capacity solution with 'macro parity' features so that operators can reduce operational and management costs associated with running multi-layer networks. The company has focused its efforts on multi-band small cells for higher capacity carrier applications. With the next-generation LampSite, Huawei is targeting other regions including Europe where RAN sharing is more common.

IBWave (acquired by Corning)

IBWave provides modeling and planning services and software tools for mobile operators and system integrators to develop in-building wireless solutions. The IBWave database includes DAS solutions, small cells, repeaters, and most recently Wi-Fi as a comprehensive toolkit to plan a wide variety of in-building options. With Corning's acquisition in 2015, it is now a wholly-owned subsidiary of Corning Optical Communications business unit. The company has been growing its Wi-Fi tools business in conjunction with traditional cellular RF planning used often by DAS system integrators.

ip.access

Femtocell vendor ip.access has successfully penetrated the enterprise and rural/remote markets, as well as its longstanding residential success with AT&T Wireless and a few other mobile operators. With a recent investment from a private equity and several product introductions, including LTE access points covering more frequency bands to cover more markets, and the Viper platform to ease the enterprise small cell deployments, the company is looking to accelerate its growth. In a competitive marketplace with similar marketing messages around virtualized RAN with ease of deployments, it will likely come down to robust product features and tactical executions.

JMA Wireless

JMA Wireless, based in Liverpool, NY, acquired Teko Telecom based in Italy in April 2013, and since then has been successful in penetrating the US market for stadium DAS. JMA installed major DAS systems in stadiums in Philadelphia and Santa Clara within the first year. The company is also highly focused on the hospitality market. With cost-optimized solutions and expanding distribution partnerships, the company has seen a strong growth in recent years. At MWC 2018, the company announced its VRAN BBU product called XRAN which runs on Intel Xeon processor.

Juni Networks

With a research and development center in Korea, Juni has been developing LTE small cells based on Intel platform since 2009. It is focusing on CBRS market and has a trial ongoing in this space. Juni has joined the CBRS Alliance in recent years.

Kathrein

Kathrein, based in Rosenheim, Germany, is entering the market for in-building wireless, with a long track record of high-quality antennas and other products in the outdoor macro market. Kathrein introduced the K-BOW DAS system and started its go-to-market in Europe with focused band support in 1800 and 2600 MHz. Starting this year, the company expanded the frequency band support and high-power (20W) remote unit to address additional markets and use cases. The company has gained some market success in the EMEA region.

Mobilitie

Mobilitie is one of the largest private wireless infrastructure providers in the US. After selling outdoor tower assets to SBA in 2012, it has funded, designed and operate several large in-building projects along with some outdoor deployments. It provides wireless infrastructure, in some key sporting venues, including the Verizon Center in DC, Arrowhead Stadium, Churchill Downs and many other venues. In many cases the company takes the

role of a neutral host, providing the funding for initial deployment. Recently the company has been associated with Sprint's small cell deployments.

NEC

NEC has successfully deployed significant numbers of indoor and outdoor small cells for Softbank and other operators in Japan, but outside of Japan, the company focuses more on the gateway. NEC sells a femtocell Node B for HSPA applications using the I-uh standard but has also developed an IMS-based femtocell for Softbank's deployment in Japan. NEC has successfully partnered with SpiderCloud to offer 3G/LTE and LTE-LAA solutions for the enterprise segment. NEC has partnerships with Netgear and Cisco, as well as core network integration relationships with Kineto, Tatara Systems, and Genband. The company has fairly mature LTE outdoor small cell products and lower cost in-building solutions for enterprise. NEC's challenges are in cost and marketing to international operators.

Nextivity

Founded in 2007 and based in San Diego, CA, Nextivity supplies high-performance carrier-specific repeaters that are designed to coexist with macro networks without interference. The company has been "authorized" by almost 200 mobile operators worldwide and has products certified by the FCC. The company's QUATRA product which leverages active DAS principles has gained traction with system integrators looking to deploy in low to mid-size venues, generally less than 500K sq. foot, using "off-air" configuration. The company believes that it will see more small cell driven deployments in the coming years to tackle more high-capacity venues.

Nokia

Nokia's primary business focuses on infrastructure for the macro layer, but the company has jumped into the small cell game as well. Nokia has been more successful in outdoor deployment than with indoor small cells. While it uses Qualcomm's SoC for its residential small cell product line, it has begun to leverage its own ReefShark SoC for a full suite of radios ranging from Macro to Carrier Outdoor and Indoor units. With the common hardware and software stack, this "macro parity" feature has been a key differentiator in its small cell products.

OpenCell

Based in the UK, OpenCell provides indoor mobile infrastructure as a managed service. The company targets small enterprises less than 50,000 square foot with Enterprise Femtocells. The company has established interconnection arrangement with major UK operators and provides a complete turnkey solution to enterprises, from design, installation, and management.

Ruckus Wireless (acquired by ARRIS)

Ruckus Wireless runs as a wholly-owned subsidiary of ARRIS. The company uses adaptive antenna technology to differentiate its carrier-class Wi-Fi access points. More recently, the company has been investing heavily in its CBRS small cell product portfolio and leveraging ARRIS' strong ties with cable MSOs to partner on cable players' wireless initiatives including CBRS outdoor small cells, and possibly CPE units for an indoor play.

Samsung

Samsung has deployed millions of CDMA femtocells in North America, with both Sprint and Verizon Wireless using the Samsung "UbiCell" for initial deployments. Samsung also supplied picocells for WiMAX networks, so they have easily converted to LTE small cell products, which have been selected by Sprint and a few other operators for ongoing LTE deployment. Most recently, Samsung has partnered with Qualcomm to support LTE-U/LAA capable femtocells. Samsung has been a key infrastructure supplier for Reliance Jio's LTE rollout and looks to expand its infrastructure business in North America with learnings from the Jio network buildout. Samsung has a portfolio of residential, enterprise, and carrier-grade small cells along with its macro product line used in the Jio rollout.

SerComm

Sercomm offers residential and enterprise small cells as well as Wi-Fi routers as a Taiwanese ODM. The company has taken the obvious step of integrating their Wi-Fi router and femtocell products together. Recently the company has focused on China and TD-LTE applications and supplies TD-LTE and FDD-LTE small cells to that market. The company has also developed CBRS-capable small cell for the North American market.

SOLiD Technologies

SOLiD developed fiber optic DAS and remote radio head products over a period of 12 years in Korea and has grown quickly in the American market. The company has fiber-based indoor DAS systems as well as high-power radio units (20W) for outdoor applications. The company has patented WDM fiber solutions which give them an advantage in fiber efficiency, especially for complex DAS installations. The company has announced its GENESIS DAS product line targeting for enterprises. The platform leverage structured cabling and low-power programmable remotes supporting four to six bands.

Spidercloud Wireless (acquired by Corning)

SpiderCloud has been in commercial service since December 2011 and has major customer wins with America Movil, AT&T, Sprint, Verizon, and Vodafone. The company is seen as a major player in the enterprise segment with expanding product features and spectrum bands, including LTE-U/LAA, CBRS, MulteFire, Private LTE, etc. The company is focused on

enterprise networks, using a centralized controller to coordinate clouds of licensed/unlicensed/shared LTE radio nodes attached via Ethernet LAN/WAN transport. The company has established a key partnership with Cisco, where they work together to outfit both indoor and outdoor Cisco Wi-Fi APs in the field with "plug-in" modules. The company was acquired in 2017 by Corning to enable the provisioning of total cellular solutions to enterprises.

Sunwave

Sunwave Solutions is a wholly-owned unit of Sunwave Communications, a Shenzen-based manufacturer of communication equipment. The parent company has about 1000 employees and reported 1.18B RMB (~$190M) in 2017. Sunwave Solutions provides a suite of active DAS and small cell solutions for carrier and enterprise applications. The company has deployed its digital DAS solution in underground metro stations in Malaysia supporting seven mobile operators.

Surecall

Surecall provides repeaters in the US market, with a focus on enterprise applications. The company has FCC certified products for enterprise, home, and automotive applications and has achieved significant deployments in corporate and college campus scenarios and continues to see robust demand for its products and is expanding its distribution partnerships including its most recent one with Authorized Integrators Network (AiN) group.

Westell

Westell offers DAS equipment, TMAs, electrical support equipment, and services for operators engaging in the in-building market. Since acquiring Cellular Specialties, Inc. in 2014, the company has restructured to return to profitability. It has refocused the organization to target traditional BDA and Public Safety market segments.

Wilson Electronics

Wilson Electronics operated for years as the largest, and arguably, the most legitimate of the unauthorized cellular repeater suppliers in North America. Wilson was involved in the repeater industry's effort to be FCC "authorized." It has since achieved FCC certification for their consumer products, with the majority of revenue shifting over to certified products during 2014. Wilson has a large network of dealers/installers in the US market. The company acquired zBoost in early 2015 as a "value" product line, while its branded WeBoost act as a "premium" class product. It also has enterprise-targeted product line under Wilson Pro branding. It offers different classes (power levels to target different size venues) of Wilson Pro bi-directional amplifiers or boosters.

Zinwave

Zinwave is a Dallas-based company focused on providing in-building wireless solutions for cellular and public safety connectivity. Zinwave provides the enterprise market a turnkey solution which includes: professional services including design, project management, and installation; the RF source; DAS solution covering public safety, cellular and CBRS bands. The company also offers so-called Cellular as a Service (CaaS)™ for funding options, and a Network Management System for system monitoring and maintenance. Zinwave's DAS solution consists of five components and supports frequencies from 150MHz to 2.7GHz on one remote hardware layer. Zinwave customers include global Fortune 100 companies and span a wide array of industries including commercial real estate, technology corporate campuses, healthcare, hospitality, airports, universities, public venues, casinos and even yachts.

ZTE:

ZTE offers a complete line of small cell products and Macro infrastructure solutions. The company also recently touted Qcell (DRS architecture) solution win at China Telecom. The ZTE product line is based on software-defined radios based on Texas Instruments SoCs which have the horsepower to run macro-level software for ideal coordination in a multimode HetNet. The recent US sanction on supplier parts to ZTE, including underlying chipset solutions, putting great uncertainty in ZTE's overall business.

10 ACRONYMS

2G: Second Generation Cellular

3G: Third Generation Cellular

3GPP: Third Generation Partnership Project

4G: Fourth Generation Cellular

AP: Access Point (often referring to Wi-Fi access point)

ARPU: Average Revenue Per User

BBU: Baseband Unit

BSC: Base Station Controller

BTS: Base Transceiver Station

Bits/Hz/sec: Digital bits transmitted per Hertz of bandwidth per second

CA: Carrier Aggregation

CAT-5: Category 5 Ethernet cable

CBRS: Citizens Broadband Radio Service, a shared wireless broadband use of the 3550-3700 MHz (3.5GHz) band in the US

CDMA: Code Domain Multiple Access, a 2G radio interface

CoMP: Coordinated MultiPoint

CPRI: Common Public Radio Interface, a non-profit organization and interface format

CPU: Central Processing Unit

CRAN: Centralized Radio Access Network (referenced in context of Centralized Baseband BBU pooling)

DAS: Distributed Antenna System

dBm: Decibels of power relative to 1mW

DRS: Distributed Radio System, a form of single-operator RRH (e.g., Ericsson Radio Dot, Huawei's LampSite)

eICIC: Enhanced Inter-Cell Interference Coordination

eLAA: Enhanced LAA (as defined in 3GPP release 14)

EMEA: Europe, Middle East and Africa

eNB: e Node B, or the radio access node for LTE

FDD: Frequency Division Duplexed

GAA: General Authorized Access, applicable for the 3.5GHz shared spectrum, the lowest priority access, similar to unlicensed spectrum use

GB: Gigabyte

GHz: Gigahertz

GkM: Gbps per square kilometer per MHz, a traffic density gauge

GSM: Global System for Mobile communications, a 2G radio interface

GW: Gateway (normally referring to a femto gateway)

HetNet: Heterogeneous Network

HSPA: High Speed Packet Access

HSPA+: A subsequent evolution of HSPA with higher throughput

Hz: Hertz (cycles per second)

IDAS: Indoor Distributed Antenna System

IoT: Internet of Things

I-ub: Interface standard for base stations

I-uh: Interface standard for femtocell to serving gateway

Km: Kilometer

LAN: Local Access Network

LTE: Long Term Evolution, a "4G" radio interface based on orthogonal frequency division multiplexed data

LTE-A: LTE Advanced, a higher bandwidth version of LTE

LAA: LTE-License Assisted Access, a 3GPP-compliant "official" LTE-U technology

LTE-U: LTE-Unlicensed, an "unofficial" technology to run LTE waveform on 5GHz unlicensed spectrum band

MOCN: Multi-Operator Core Network, a network sharing method at a core network level

MORAN: Multi-Operator Radio Access Network, a network sharing method at a radio network level

OBSAI: Open Base Station Architecture Initiative, a non-profit organization and interface format

OEM: Original Equipment Manufacturer

MAC: Media Access Control layer

MHz: Megahertz

MkM: Mbps per square kilometer per MHz

MIMO: Multiple Input, Multiple Output

MOCN: Multi-Operator Core Network

MORAN: Multi-Operator Radio Access Network

MS: Mobile Station

mW: Milliwatt

OBSAI: Open Base Station Architecture Initiative

O-DAS: Outdoor Distributed Antenna System

OEM: Original Equipment Manufacturer

OFDM: Orthogonal Frequency Division Multiplexed

OTA: Over the Air

node B: A radio base station for WCDMA/HSPA

PAL: Priority Access License, applicable for the 3.5GHz band, second highest priority in use of the 3.5GHz shared spectrum

PC: Personal Computer

QoS: Quality of Service

RAN: Radio Access Network

RF: Radio Frequency

RNC: Radio Network Controller

RRH: Remote Radio Head

SAS: Spectrum Access System, a software system to coordinate spectrum sharing (although it can be applied across all shared spectrum, its use is primarily focused on 3.5GHz CBRS)

SINR: Signal-to-Interference-plus-Noise Ratio (quality of wireless communication)

SIP: Session Initiation Protocol

SNR: Signal-to-Noise Ratio

TB: Terabyte (1000 GB)

TD-LTE: Time Domain based Long Term Evolution

TD-SCDMA: Time Domain Synchronous Code Domain Multiple Access

TV: Television

UE: User Equipment

VAR: Value Added Reseller

VRAN: Virtualized Radio Access Network

W: Watts

WCDMA: Wideband Code Domain Multiple Access, a 3G radio interface

Wi-Fi: Wireless Fidelity (802.11 data communications)

11 METHODOLOGY

Mobile Experts combined the forecasts from five separate market areas in this overall in-building market study. We based the quantitative forecast on our deep-dive publications in each specific area:

- *Global DAS Market*, September 2017 (forecast updated April 2018)
- *Small Cells 2018* (April 2018)
- *CRAN and VRAN 2017: Centralization and Virtualization* (April 2016)
- *Carrier Wi-Fi and LTE-U*, October 2017
- Plus independent market analysis of Boosters

In this analysis, we emphasized the economic analysis of various options against each other. We examined multiple case studies to ascertain the most cost-effective alternative for the mobile operator, for the neutral host, and for the enterprise. We have based our balanced forecasts on these comparisons, by estimating how many decision-makers in each group will influence a chunk of the market.

Finally, we interviewed multiple building owners and system integrators to understand the trend toward infrastructure purchases by the enterprises themselves. We conducted interviews related to each vertical market in order to understand the relevant factors and the likelihood of growth.

In each of our individual market studies, Mobile Experts interviews at least 20-30 mobile operators, and compares the top-down input received from operators with the bottom-up inputs from OEMs and semiconductor suppliers. The key element in most Mobile Experts forecasts is simple: If we don't see demand from the operators showing up at the semiconductor level, then it's not real.

In this comparative study, Mobile Experts focused exclusively on the indoor mobile infrastructure options that support enterprise applications. We have taken each technology area (DAS, Small Cell, DRS, Repeater), and evaluated how many in-building radio nodes are used to support an enterprise, and how many are used for the carrier's general public coverage. We then broke down each radio solution to understand how many units will be purchased by the enterprise and deployed by the enterprise, to illustrate the changing business model.

This report simplifies the forecast by focusing only on radio shipments. Full coverage of revenue, pricing, and market shares can be found in the full Mobile Experts market studies.

Definitions	Description
DAS	A network of radio nodes for mobile communications, using a simulcast of identical RF waveforms from a hub.
Heavy DAS	DAS with the support for 6-8 bands across 3-4 operators
Light DAS	DAS with a single band for multiple operators (or for a single operator)
Multioperator	DAS systems configured to allow multiple mobile service providers to use the same distribution and radio nodes.
Small Cell	Network nodes which transmit less than 30W of composite power per sector, which include baseband processing for complete enodeB/nodeB/BTS functionality.
Femtocell	The term "femtocell" refers to a residential/SOHO unit which works autonomously without much coordination and handover to the macro network
DRS	Distributed Radio Systems use twisted-pair cables to distribute radio signals to various antenna nodes in a building, with a central remote radio head to process the radio signals. Radio Dot uses RF over twisted pair. LampSite uses I/Q samples over twisted pair. Both examples are listed in the Mobile Experts category for RRH, but we count the number of DRS nodes in this report to illustrate the coverage of these systems.
Low Power RRH	A Remote Radio Head which connects to a macro base station baseband processing center via digital I/Q interface, typically over optical fiber. Unless designated as a "Split Baseband RRH", an RRH uses CPRI or a similar interface between PHY baseband and RF. A Low Power RRH transmits less than 300 mW for indoor applications.
Split Baseband Low Power RRH	processing center via digital I/Q interface, typically over optical fiber. A Split-Baseband RRH includes some baseband processing, normally in the PHY and MAC areas, but with other baseband processing located centrally. A Low Power RRH transmits less than 300 mW for indoor applications.
IDAS	Indoor DAS, transmitting less than 10W of composite power per node. Note that some low-power nodes will be physically outdoors but are still categorized as "indoor" based on power level.
Booster	A radio receiver and transmitter which boosts the bi-directional signal power for a local user without higher level baseband processing
Broadband Booster	A broadband repeater generally receives and retransmits all of the RF signals within a given band (multiple operators)
Carrier Specific Booster	A repeater endorsed by mobile operators, which generally use filters and DSP to isolate the signals for a specific mobile service. The unit can be purchased either by the operator or by an enterprise but is endorsed by the operator.
VRAN (BBU)	"White-box" server running virtualized baseband software

Figure 30. Key definitions for terms